# U.S. Coast Guard Research and Development Center

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**Report No. CG-D-01-05**

EVALUATION OF BIOCIDES FOR POTENTIAL
TREATMENT OF BALLAST WATER

**FINAL REPORT**

**OCTOBER 2004**



Prepared for:

U.S. Department of Homeland Security
United States Coast Guard
Marine Safety and Environmental Protection (G-M)
Washington, DC 20593-0001

# N O T I C E



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16. Abstract (MAXIMUM 200 WORDS)

This report documents the investigation, characterization, and evaluation of biocides that demonstrate potential for ballast water treatment application. A literature search was conducted for information on various aspects of biocides, including their biological treatment efficacy, environmental acceptability, and shipboard safety and practicality, and regulations governing them. Vendors and manufacturers of biocides were also contacted, in order to obtain the most recent data regarding the candidate biocides. The information was organized into a searchable relational database designed to generate a fact sheet for each biocide, summarizing a series of evaluation criteria. Each biocide was evaluated to determine its applicability to ballast water. Chlorine dioxide, glutaraldehyde, SeaKleen®, and cationic surfactants were identified as potential ballast water treatment agents for marine and freshwater use. Copper, bromine, iodine, sodium chlorite, chloramines, ozone, formaldehyde, ethylene oxide, and Dowacil® 75 were determined to be poor biocidal options for ballast water treatment. Several other biocides demonstrated some efficacy but further research would be required before they could be characterized. The recommendations offered to support future decisions on biocide use include continuing research on environmentally-friendly chemicals for use as biocides, conducting experiments on the effects that marine conditions could have on the efficacy and fate of those biocides, and encouraging pilot-scale design studies of ballast water biocidal treatment processes.

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## Executive Summary

The introductions of nonindigenous aquatic nuisance species (ANS) have had profound negative impacts on aquatic ecosystems worldwide. One of the major vectors for the introduction of ANS is the discharge of ships' ballast water. In normal shipping operations, ballast water is brought aboard or discharged to adjust the total ship weight, compensating for changes in cargo and fuel loads, which in turn adjusts and optimizes ship characteristics such as hull bending moment, draft, hull loading, and propulsive efficiency.

The U.S. Coast Guard (USCG) is in the process of developing a program for approving multiple environmentally sound methods of ballast water management that will prevent and control ANS introductions during ballast water discharge. Environmentally sound methods of ballast water management that are under investigation worldwide include filtration, hydrocyclonic separation, ultraviolet (UV) radiation, ultrasound, deoxygenation, biocides, and thermal treatment.

Treatment of ballast water with biocides is an attractive option due to their potential for eradicating a broad range of organisms and the potential ease of incorporating the technology into existing and future vessel designs. However, information on potential biocides has not been compared against a common set of criteria, even though biocides have been used extensively for drinking and wastewater disinfection and the body of literature supporting these applications is considerable. The use of biocides to the ballast tank environment is different from these applications and the ballast tank and water may not be compatible with certain biocides. Moreover, few studies have been conducted on the feasibility of using these biocides to treat the range of organism types found in estuarine and ocean water.

To address the effectiveness and practicality of biocides to treat ballast water for the organisms in marine waters, USCG requested an evaluation of biocides with the potential to eliminate viable organisms in ballast water that could pose an ecological or economic threat to coastal waters. Currently, there are no state or federal permitting requirements for ballast water discharges. In fact, point-source discharge regulations provide exemptions for ballast water discharges. However, discharges of ballast water treated with any biocide would need to be of such quality so as to protect the designated uses of receiving waters. Before approving any biocides for ballast water treatment, USCG needs to understand what biocides and byproducts are regulated at the state, federal, and/or international levels, how they are being regulated (e.g., maximum discharge limits), and by whom. Therefore, USCG requested information regarding international conventions and United States laws and regulations for the use of biocides. This report documents the characteristics of biocides that have potential application for ballast water treatment, as well as the regulations governing them.

A literature search was conducted to obtain information on various aspects of biocides, including their biological treatment efficacy, environmental acceptability, shipboard practicality and safety, cost of raw materials, and regulations. The literature search was not restricted to seawater and included the use of biocides in freshwater, wastewater, and industrial water systems. The search also included biocides commonly used in marine antifouling paints.

A total of 32 chemicals that are used as biocides in various applications were identified for characterization. The information on these biocides was reviewed and organized into a searchable relational database based on a specific set of evaluation criteria. These criteria were developed to provide a consistent means of comparison and to help guide the assessment of each identified biocide in its potential application for ballast water treatment. The criteria included:

- Dosage/toxicity information
- Inhibitors/interferences to/with biocide reactivity
- Efficacy on classes of organisms
- Stability of the biocide
- Biocide degradation/byproducts (rates and causes) and environmental acceptability
- Crew safety
- Availability of the biocide (includes whether the biocide is a common commercial product, a specialty product, etc.)
- Shipboard application considerations (e.g., on board storage, on board generation, biocide unit costs [i.e., $/unit volume or mass])
- Conventions, laws, and regulations governing the use of biocides

The database was designed to generate a fact sheet for each biocide. Information for each biocide was then evaluated using a set of qualitative rankings to assess how the various characteristics of a given biocide might be advantageous or disadvantageous for ballast water treatment.

This study identified a number of questions regarding biocide use in ballast water that must be addressed before widespread use can be sanctioned. For example, factors such as the degradation rate of a particular biocide and the potential release of undesirable byproducts into the receiving waters are not well documented for marine waters. Also, many of the physical and chemical properties of seawater raised questions about whether some biocides can be applied effectively to marine waters. Moreover, the safe use of biocides on board ships, their compatibility with ballast tank structural materials are not well understood. Due to the limited available information on biocide use in the marine environment, the effectiveness of biocides in treating ballast water is uncertain. In spite of these data shortcomings, several biocides did show potential for use in treating ballast water. Several biocides were also identified as having poor potential for ballast water applications. Other biocides were identified as chemicals requiring additional information before their potential for ballast water treatment could be evaluated.

The results of the qualitative evaluation for individual biocides are as follows:

- Chlorine dioxide, glutaraldehyde, SeaKleen®, and cationic surfactants, such as $C_{16}$-alkyltrimethylammonium chloride, were identified as potential agents for ballast water treatment in both marine and freshwater environments;
- Copper, bromine, iodine, sodium chlorite, chloramines, ozone, formaldehyde, ethylene oxide, and Dowicil® 75 were determined to be poor potential biocides for ballast water;
- Mexel® 432, Dibromonitrilopropionamide (DBNPA), Polyhexamethylene biguanide (PHMB), 2-thiocyanomethylthio benzothiazole (TCMTB), benzalkonium chloride, chlorine, chlorothalonil, dichlofluanid, Grotan®, hydrogen peroxide, potassium

permanganate, silver, Peraclean®, zinc pyrithione, Irgarol® 1051, phenol, triclosan, and zineb were identified as biocides with demonstrated efficacy against some of the target organisms, but recommending these biocides for ballast water treatment requires information regarding other evaluation criteria;

- Sea-Nine® (also known as Kathon®) was identified as an antifouling agent with potential efficacy against target organisms, but information regarding its efficacy in water was not available in the literature reviewed;
- Intersmooth® was identified as an antifouling agent with potential efficacy against target organisms, but because this compound is an organotin, its use for treating ballast water is limited by certain federal and national laws. Therefore, this biocide was not evaluated in this report.

Because much of the information obtained from the literature search was not specifically the result of scientific research targeted for ballast water treatment, the use of this information to determine ballast water applicability should be used cautiously. The following recommendations are made to support future decisions on the applicability of biocide use in ballast water:

- Continue research using environmentally friendly chemicals as biocides in the marine environment.
- Conduct laboratory bench-scale studies aimed at the effects of marine environmental conditions, efficacy, and fate of potential biocides.
- Encourage pilot-scale design studies of ballast water biocidal treatment processes.

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## List of Acronyms and Abbreviations

| | |
|---|---|
| AISE | Association Internationale de la Savonnerie |
| ANS | aquatic nuisance species |
| AWWA | American Water Works Association |
| BWM | ballast water management |
| °C | degrees Celsius |
| CFR | Code of Federal Regulations |
| CPO | chlorine-produced oxidants |
| CTI | Cooling Technology Institute |
| DBNPA | dibromonitrilopropionamide |
| DOT | United States Department of Transportation |
| EC | European Community |
| $EC_{50}$ | effective concentration at which 50% of test organisms are affected |
| EEZ | exclusive economic zone |
| ENEV | estimated no-effects value |
| ESA | Endangered Species Act |
| FIFRA | Federal Insecticide, Fungicide, and Rodenticide Act |
| h | hours |
| IMO | International Maritime Organization |
| $LD_{50}$ | lethal dose that kills 50% of the organisms tested |
| $m^3$ | cubic meter |
| MBARI | Monterey Bay Aquarium Research Institute |
| mg/L | milligrams per liter |
| mg-min/L | milligrams per minute per liter |

## List of Acronyms and Abbreviations continued

| | |
|---|---|
| MPRSA | Marine Protection, Research, and Sanctuaries Act |
| MSDS | Material Data Safety Sheet |
| NOAA | National Oceanographic and Atmospheric Administration |
| NPDES | National Pollutant Discharge Elimination System |
| OSHA | Occupational Safety and Health Act |
| OSPAR | Convention for the Protection of the Marine Environment of the North-East Atlantic (Oslo-Paris Commissions) |
| PHMB | polyhexamethylene biguanide |
| ppm-Cl | parts per million of chlorine |
| TBT | tri(butyl) tin |
| TCMTB | 2-thiocyanomethylthiobenzothiazole |
| TDS | total dissolved solids |
| THM | trihalomethane |
| µg/L | micrograms per liter |
| USCG | United States Coast Guard |
| U.S. EPA | United States Environmental Protection Agency |
| UV | ultraviolet |

## 1.0 Introduction

Introductions of non-indigenous aquatic nuisance species (ANS) have had profound negative impacts on aquatic ecosystems worldwide. This impact is particularly evident in the coastal regions of the United States (including the Great Lakes) where introductions of ANS have altered important ecological processes and caused serious economic damage. Nonindigenous species (also known as introduced, invasive, exotic, alien or aquatic nuisance species) are defined as "any species or other viable biological material that enters an ecosystem beyond its historic range, including any such organisms transferred from one country into another" (National Resource Council (NRC), 1996). These species affect their new environment and native species through competition for food or habitat, predation of organisms, overgrazing, alteration of nutrient cycles or soil fertility, increased erosion, pathogen introduction, or hybridization with native species. Not all species that are introduced to an ecosystem are injurious or harmful to the resident biota, but it is difficult to predict which ones will have adverse effects, or to what degree the species might infiltrate. Therefore, precautions must be taken to prevent any nonindigenous species from being introduced into a new environment.

Ballast is any solid or liquid that is brought on board a vessel to stabilize it, alter its weight, and adjust its center of gravity. Ships typically use ballast water to provide stability and maneuverability during a voyage. Water is taken up at one port when cargo is unloaded and usually discharged at another port when the ship receives cargo. As organisms ranging in size from viruses to fish are taken on board with ballast water at one port, there is potential that these organisms will be released at the next port when cargo is loaded on the vessel. As ships travel faster and world trade grows, species are better able to survive the journey, and the threat of ANS increases. The United States alone receives at least 21 billion gallons of ballast water each year from around the world, leading to ecosystem-level impacts like the displacement of native freshwater mussels and alteration of the food web by *Dreissenia polymorpha* (Eurasian zebra mussel) in the Great Lakes, and the Mississippi and Hudson Rivers. *Mnemiopsis leidyi* (American comb jelly), probably transported from New England by vessel to the Black and Azov Seas in Europe, has caused drastic declines in zooplankton abundances, increased the hypoxia level, and virtually destroyed the fishing industries in its adopted environment. The recent discovery of several new ANS (Grigorovich and MacIsaac, 1999) demonstrates the urgent need for ballast water management (BWM) to reduce the risk of future introductions.

The economic, environmental, and health problems caused by nonindigenous aquatic nuisance species persuaded the United States Congress to pass legislation in 1990 and 1996 to address the issue. Under the legislation (Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA) and National Invasive Species Act of 1996 (NISA)), the United States Coast Guard (USCG) was ordered to establish regulations that would prevent further ANS introductions through ballast water into U.S. waters. The USCG has focused efforts on reducing ANS introductions via ballast water and has developed a voluntary Ballast Water Management Program. Because the voluntary nature of this program was found not effective for managing the introduction of ANS via ballast water (USCG, 2001), the USCG proposed rules that would make ballast water management mandatory, particularly for vessels that operate outside the exclusive economic zone (EEZ) before entering U.S. waters (USCG, 2003). These rules, which were finalized in August 2004, revised subpart D of 33 CFR 151 to require mandatory ballast water management for all vessels equipped with ballast water tanks entering U.S. waters after

operating outside of the EEZ. Existing mandatory BWM requirements for vessels entering into the Great Lakes and Hudson River remain unchanged. This mandatory BWM program requires all vessels to conduct one of the following BWM practices:

1. *Exchange ballast water beyond the EEZ in an area more than 200 nautical miles from any shore.*
This refers to conducting mid-ocean ballast water exchange (exchanging ballast water obtained from ports or coastal waters outside of the EEZ with mid-ocean waters) prior to ballast water discharge in U.S. waters.
   A. *Empty and refill exchange*. Ballast water taken on in ports or coastal waters outside of the EEZ is discharged until the ballast tank is empty (as close to 100 percent empty as vessel navigation and safety considerations will allow). The tank is then refilled with mid-ocean water.
   B. *Flow-through exchange*. Ballast water taken on in ports or coastal waters outside the EEZ is flushed out of the ballast water tanks by pumping in mid-ocean water at the bottom of the tank and continuously overflowing the tank at the top. This flushing continues until three full ballast water tank volumes have been pumped.

2. *Retain ballast on board the vessel.* A vessel that does not choose to conduct mid-ocean exchange may elect to retain its ballast water on board while in U.S. waters.

3. *Use an "environmentally sound" USCG-approved alternative ballast water management method before the vessel enters the U.S. EEZ.* An alternative environmentally sound method of BWM is a method, effort, action, or program that will prevent and control non-indigenous species (NIS) introductions during ballast water discharge. The USCG is in the process of developing a program for approving this type of ballast water management.

4. *Discharge ballast water to an approved reception facility.* An approved reception facility is a land-based ballast water holdingor treatment facility that is specifically used to accommodate ballast water discharge from vessels.

Environmentally sound methods of BWM that are presently under investigation by government, industry, academic, and non-governmental interests include filtration, hydrocyclonic separation, ultraviolet (UV) radiation, ultrasound, deoxygenation, biocides, and thermal treatment. However, the capabilities and limitations of these treatment technologies relative to conditions likely to be met during ballasting operations are poorly understood. This report is limited to the use of biocides as an environmentally sound ballast water treatment method.

Biocides may be added to both ballasted and non-ballasted vessels to eliminate viable organisms. Treatment with biocides is potentially attractive because the technology may be readily incorporated into both existing and future vessel designs and may be effective against a broad range of organisms. There are, however, a number of questions regarding the use of biocides to treat ballast water that must be addressed before widespread use can be sanctioned.
Factors such as the degradation rate of a particular biocide and the potential release of undesirable byproducts into the receiving waters must be known. In fact, many physical and

chemical properties of seawater raise questions on whether biocides can be applied safely to the marine environment and on board vessels. Moreover, although biocides have been used extensively in certain industries for disinfection, application in a ballast tank environment is different and may not be compatible with certain biocides. For example, some biocides may react with organic material or may be corrosive at higher concentrations. Even though the body of research regarding the successful use of biocides for control of organisms in drinking and wastewater is considerable, few studies have been conducted on the feasibility of using these biocides to treat a range of organisms in estuarine and ocean water. Thus, the effectiveness of biocides to treat marine or estuarine water for potentially invasive species is uncertain. The safe use of biocides on board ships, their compatibility with ballast tank structural materials, their potential interaction with particles, salt, or dissolved organic matter in water, and the impacts of the release of the biocide or its byproducts into the receiving waters are also not well understood. Information is lacking on environmental safety and biocide effectiveness across the range of organisms that ballast water treatment is intended to manage.

To address these and other questions concerning the ability of biocides to treat marine waters, an evaluation was conducted of biocides that might be applied to ballast water to eliminate viable organisms that could pose an ecological or economic threat to coastal waters. This report documents the investigation, characterization, and evaluation of biocides for ballast water treatment.

For clarity of presentation and understanding, it is important to define the term "biocide." Block (1991) defined biocide as "…a substance that kills all living organisms, pathogenic and nonpathogenic." He also commented that "…because a biocide kills spores as well as vegetative cells, it is presumably a sterilizing agent. The definition includes all species of living organisms, micro and macro, but the term is commonly used with reference to microorganisms." The Organization for Economic Co-operation and Development (OECD), which includes 30 member countries from Europe, North America, Australia, and Asia, considers the working definition of biocides to be "…products that have an effect on an unwanted organism but are not controlled as agricultural pesticides, veterinary medicines, medicine or in any other relevant legislation." More specifically, the European Community (EC), Biocidal Products Directive, (BPD) (98/08/EC) defines biocides as chemical preparations containing one or more active substances that are intended to control harmful organisms by either chemical or biological means (European Parliament Council, 1998). The EC definition is not firmly agreed upon as there are a number of scope issues, such as the range of compound complexity, lack of risk assessment tools, and efficacy data that have yet to be resolved. In the United States, the majority of the "EC biocidal product types" are known as "anti-microbials" (e.g., disinfectants, sanitizers, and pesticides). For this study, "biocide" is defined as those chemicals available off-the-shelf or generated aboard a vessel by a physical process, such as electro-ionization, or by mixing of two or more chemicals that are used to control or inactivate unwanted organisms.

The recently passed International Convention for the Control and Management of Ship's Ballast Water and Sediments (International Maritime Organization (IMO) February 13, 2004) includes requirements for the use of active substances, meaning chemical or biological biocides (IMO, 2004). A number of such biocides are presently under investigation for use in ballast water treatment. Examples of biocides include chlorine-based treatments (e.g., chlorine gas, chlorine dioxide, chloramines), glutaraldehyde, peroxide, ozone, copper, SeaKleen® (vitamin K), and

Peraclean® (peracetic acid). Although these biocides are included in this study, the investigation was not restricted to these.

### 1.1 Organization of the Report

The report is organized into seven sections. Section 1 includes this introduction and additional background information. Section 2 describes the literature search and the database development conducted for the investigation phase of the evaluation. Section 3 identifies and characterizes the biocides identified through the literature search. Section 4 presents the evaluation of the biocides using a set of specific criteria that were developed to characterize and rank the various biocides. Section 5 describes the application of biocides to ballast water treatment. Section 6 summarizes the findings and recommendations and Section 7 lists the references cited in this report. Appendix A provides a discussion of the interactive database developed to house information gathered for the investigation. Appendix B provides fact sheets with detailed information on each biocide investigated.

## 2.0 Literature Search

The investigation began by conducting a literature search to identify potential biocides and to obtain available information on various aspects of biocides, including their biological treatment efficacy (i.e., the ability to kill or otherwise inactivate organisms), environmental acceptability, shipboard practicality, and cost of raw materials. The literature search also included antifouling agents to provide a comprehensive list of chemicals with potential biocidal applications. Antifouling agents are biocides that are typically added to the paint used to coat the outside of a vessel's hull to prevent organisms from growing or attaching themselves to the hull. In addition, information regarding international conventions and United States laws and regulations for the use of biocides was obtained.

The literature search began by conducting preliminary searches based on key words and phrases associated with biocides and biocide characteristics. The literature search employed general Internet searches, as well as searches of dedicated literature tools, such as Scifinder® (Chemical Abstract Services) and Sciencedirect® (Elsevier). The Internet search included major search engines, as well as specific web sites, including those for the United States Environmental Protection Agency (U.S. EPA), American Water Works Association, the environmental protection agencies of Canada, New Zealand, and Australia, West Coast Ballast Outreach Project, U.S. Federal Register, and various technical websites containing relevant information such as the Global Ballast Water Management Program and the North American Pesticide Action Network (PAN) Pesticides Database. Table 2-1 illustrates some of the web sites visited during the Internet searches. Many of the web sites encountered provided links to other relevant sites that included literature, proceedings from workshops/symposiums, vendor information, and other information on biocides.

**Table 2-1. Summary of Web Sites Containing Key Information.**

| Web Sites | Information Obtained |
|---|---|
| http://www.anstaskforce.gov/toc.htm | ANS Task Force |
| http://www.aquahabistat.com | Aquihabistat |
| http://www.pml.ac.uk/ace/default.htm | Assessment of Antifouling Agents in Coastal Environments (ACE) |
| http://www.affa.gov.au | Australian Government Department of Agriculture, Fisheries, and Forestry |
| http://www.awwarf.com | American Water Works Association (AWWA) Research Foundation |
| http://massbay.mit.edu/exoticspecies/ballast/ref.html | Ballast Water References |
| http://www.nemw.org/Ballast%20Water%20Vendors.pdf | Ballast Water Technology Treatment Vendors from the Northeast-Midwest Institute website |
| http://www.biochem.techdevices.co.uk | Biochem Products Ltd |
| http://www.chemflow.com/web/cfhome2.nsf/publicgeneralinfo/10 | Biocide information center at Chem Flow |
| http://www.greenmarineinc.com/epbromination.html | Bromination Vendor |
| http://c3.org/chlorine_issues/disinfection/disinfection_index.html | Chlorine issues |
| http://www.coatingsworld.com | Coatings World |
| http://www.cqdjournal.com | CQD Journal for the Maritime Environment Industry (E.M. Miller Associates, Inc.) |
| http://www.cti.org/ | Cooling Technology Institute bibliography of technical papers |
| http://www.electrichlor.com | Electrichlor |
| http://www.clo2.com | ERCO™ Worldwide chlorine dioxide water treatment resource center |
| http://globallast.imo.org/Abstracts | Global Ballast Water Management Programme 1st International Ballast Water Treatment R&D Symposium |
| http://globallast.imo.org | Global Ballast Water Management Programme Search Projects |
| http://www.haloztechnologies.com | Halox Technologies, Inc. |
| http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB | Hazardous Substances Databank |
| http://www.hydemarine.com/ballast/seakleen.htm | Hyde OptiMarin for SeaKleen® |
| http://www.inchem.org/ | International Programme on Chemical Safety |

**Table 2-1. Summary of Web Sites Containing Key Information (cont'd).**

| Web Sites | Information Obtained |
|---|---|
| http://www.imarest.org | The Institute of Marine Engineering, Science and Technology (IMarEST) 2nd International Ballast Water Treatment R&D Symposium |
| http://www.mepi.net | Marine Environmental Partners, Inc. |
| http://www.michigan.gov/mesb/ | Michigan Environmental Science Board Department of Environmental Quality |
| http://www.mbari.org | Monterey Bay Aquarium Research Institute (MBARI) News |
| http://www.glerl.noaa.gov | National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory |
| http://www.ballastwater.com/BWPapers.htm | OptiMarin A/S Optimar Ballast Systems |
| http://www.clr.pdx.edu/projects/ballast_water/ballast_intro.html | Oregon Ballast Water program |
| http://www.pesticideinfo.org | PAN Pesticides Database |
| http://www.performance-chemicals.net | Performance Chemicals Ltd. |
| http://www.pml.ac.uk/ | Plymouth Marine Laboratory |
| http://www.rohmhaas.com/seanine | Sea-Nine® product |
| http://www.slc.ca.gov/ | State of California |
| http://www.tramfloc.com | TRAMFLOC™, INC. (chlorine product vendor) |
| http://www.epa.gov/OGWDW/index.html | U.S. EPA Drinking water program |
| http://www.epa.gov/ecotox/ | U.S. EPA ecotoxicity information |
| http://www.epa.gov/pesticides/factsheets | U.S. EPA pesticides program |
| http://www.h2o2.com | USPeroxide |
| http://www.hopkins-heic.org/infectious_diseases/water_table.htm | Water disinfection |
| http://www.accepta.com | Water treatment at Accepta |
| http://www.myregs.com/dotrspa/ | U.S. Department of Transportation Regulations |

The literature search was not restricted to seawater but included drinking water, wastewater, and industrial water to derive a list of biocides potentially applicable to ballast water treatment. In the course of the study, several peer-reviewed articles were also identified and examined.

To obtain additional information on biocides, various treatment technology vendors were contacted and asked the following questions:

- What is the specific biocide(s) used in the vendor's technology?
- What are the target species?
- What is the required dosage?

- What are the concentrations and the contact time?
- What percentage reduction is achieved with vendor's biocide?
- Do pH levels affect the biocide?
- Is the biocide affected by temperature?
- Is the biocide affected by salinity?
- Is the biocide affected by total dissolved solids (TDS)?
- Is the biocide affected by organic matter?
- Is the biocide affected by turbidity?
- What are the residual concentrations of the biocide in treated water?
- What is the method of organism inactivation?
- Is the biocide recalcitrant? If so, what is the nature of this recalcitrance?
- Are byproducts generated?
- Are there compatibility issues with vessel structure?
- Can this technology be used in freshwater as well as saltwater?
- What is the skill level or training requirements needed?
- What sort of maintenance is required?

Table 2-2 provides a summary of all the vendors contacted. The responses provided by each vendor are included in the fact sheets (Appendix B).

**Table 2-2. Summary of Vendors Contacted.**

| Vendor | Phone | Website |
|---|---|---|
| Accepta | +44 (0) 1625 267 581 | www.accepta.com |
| Electrichlor | (574) 773-8921 | http://www.electrichlor.com |
| GDT Corporation | (623) 587-8858 | www.gdt-h2o.com |
| Marine Environmental Partners | (561) 842-9900 | www.mepi.net |
| Maritime Solutions, Inc | (212) 747-9044 | http://www.maritimesolutionsinc.com |
| Miox Corporation | (505) 343-0090 | www.miox.com |
| Optimarin A/S | (203) 973-0678 | www.optimarin.com |
| Pentair Water Treatment/ Plymouth Products | (800) 222-7558 | www.plymouthwater.com; www.pentairwater.com |
| Severn-Trent | +44 (0) 121 722 4000 | www.severn-trent.com |
| Tandem Technologies | (301) 805-6823 | http://www.tandemtechnologies.com |

## 2.1 Database Development

The information gathered from the literature search was reviewed and organized into a searchable relational database (Microsoft Access®) based on a specific set of evaluation criteria. The criteria were developed to provide a consistent means of comparison and to help guide the assessment of each identified biocide in its potential application for ballast water treatment.

These criteria include:

- Dosage/toxicity information
- Inhibitors/interferences to/with biocide reactivity
- Efficacy on the major classes of organisms present in fresh and marine water ecosystems (viruses, bacteria, protozoa, fungi, zooplankton, algae, seaweeds, invertebrates, and fish)
- Stability of the biocide
- Degradation/byproducts of the biocide (rates and causes) and environmental acceptability
- Personnel Safety
- Availability of the biocide (includes whether the biocide is a common commercial product, specialty product, etc.).
- Shipboard application considerations (e.g, on board storage, on board generation, biocide unit costs [i.e., $/unit volume or mass]).
- Conventions, laws, and regulations governing the use of the biocide.

Vendor contact information and citations are also included in the database. For each biocide, the database allows the user to generate one fact sheet that summarizes the available evaluation criteria. The physical and chemical properties of the biocides, as well as the feasibility for shipboard use of each biocide, are included in the fact sheets. Appendix A provides a descriptive summary of this database as well as instructions for accessing and editing it. Fact sheets for each investigated biocide, as generated by the database, are included in Appendix B. Due to the limited availability of data, information on some of the evaluation criteria could not be presented in every fact sheet. Information considered useful for characterizing those biocides was lacking and requires further research and investigation.

## 3.0 Characterization and Identification of Biocides

The characterization and identification of biocides were based on the availability of information on various factors potentially affecting the suitability of the biocide for ballast water treatment. Factors influencing this suitability included chemical, physical, and toxicological properties of the biocide, as well as shipboard design characteristics, including personnel safety and application considerations.

### 3.1 Identification of Biocides

Thirty-two biocides were identified during the literature search (Table 3-1). The identified biocides included oxidizing (halogenated, non-halogenated) as well as non-oxidizing (acids, aldehydes, amines, ketones, metals) substances. Many of these biocides are currently used for treatment of drinking water, wastewater, and industrial water (e.g., cooling water, metal finishing, and others). Only a few of these biocides have been specifically evaluated for application in controlling ANS in ballast water. Active research, such as on the use of chlorine, glutaraldehyde, hydrogen peroxide, ozone, bromine, and SeaKleen® (active ingredient is vitamin K) as biocidal treatments in ballast water are currently being conducted (U.S. EPA, 2001; Glosten-Herbert-Hyde Marine, 2002; Cooper *et al*., 2002). In September 2000, for example, a prototype ozonation system was installed on the 11 million gallon-capacity oil tanker *S/T Tonsina* in an effort to analyze ozone's ability to remove ANS from marine ballast water (Cooper *et al*., 2002). The National Research Council (1996) also identified a list of chemicals

that could be added to shipboard applications to eliminate viable organisms, although data on efficacy and environmental fate are limited for these biocides. They were retained in the list of biocides to ensure completeness.

The list also includes biocides that are commonly used in marine antifoulants. Although antifoulants containing organotins were identified as biocides, because of the strict national and international regulations banning their use they were not included in the list nor in the report.

**Table 3-1. Summary of Biocides Identified.**

| Biocide | Common Application |
|---|---|
| **Metal** | |
| Copper (ionic or salts) | Disinfection of industrial water systems |
| Silver (ionic or salts) | Disinfection of industrial water systems |
| **Oxidizing** | |
| ***Halogen containing compounds*** | |
| Bromine | Disinfection of drinking water, cooling systems, and surfaces |
| Chloramines | Disinfection of drinking water, cooling systems, and surfaces |
| Chlorine | Disinfection of drinking water, cooling systems, and surfaces |
| Chlorine Dioxide | Disinfection of drinking water, cooling systems, and surfaces |
| Iodine | Disinfection of drinking water, cooling systems, and surfaces |
| Sodium chlorite | Disinfection of drinking water, cooling systems, and surfaces |
| ***Non-halogen containing compounds*** | |
| Hydrogen peroxide | Disinfection of drinking water, cooling systems, and surfaces |
| Ozone | Disinfection of drinking water, cooling systems, and surfaces |
| Potassium Permanganate | Disinfection of drinking water, cooling systems, and surfaces |
| **Non-oxidizing** | |
| ***Acids*** | |
| Peraclean® (peracetic acid) | Wastewater treatment; fungicide |
| ***Aldehydes*** | |
| Formaldehyde | Disinfectant in hospitals, laboratories, and biological fixatives |
| Glutaraldehyde | Disinfectant in hospitals, laboratories, and biological fixatives |

**Table 3-1. Summary of Biocides Identified (cont'd).**

| Biocide | Common Application |
|---|---|
| ***Amines and halogenated amides*** | |
| Dibromonitrilopropionamide (DBNPA) | Pulp and paper water treatment systems; disinfection of industrial water systems |
| Mexel® 432 (fatty amines) | Corrosion inhibitor; scale dispersant; molluscide |
| ***Heterocyclic ketones*** | |
| Polyhexamethylene biguanide (PHMB) | Disinfection of industrial water systems |
| Sea-Nine® (isothiazolone) | Antifouling agent |
| ***Others*** | |
| 2-thiocyanomethylthio benzothiazole (TCMTB) | Disinfection of industrial water systems; antifouling agent |
| Benzalkonium chloride | Disinfection of industrial water systems |
| Cationic surfactants (example: $C_{16}$-alkyltrimethylammonium chloride) | Disinfection of industrial water or wastewater treatment |
| Chlorothalonil | Antifouling agent; fungicide |
| Dichlofluanid | Antifouling agent; fungicide |
| Dowicil® 75 (N-(3-chloroallyl)hexaminium chloride) | Metalworking fluids, preservative for paints |
| Ethylene oxide | Sterilant/fumigant |
| Grotan® (Hexahydro-1,3,5-tris(hydroxyethyl)-s-triazine) | Metalworking fluids; bactericide and fungicide |
| Irgarol® 1051 (2-methylthio-4-tert-butylamino-6-cyclo-propylamino-s-triazine) | Antifouling agent |
| Phenol | Disinfectant and slimicide |
| SeaKleen® (Vitamin K) | Ballast water treatment |
| Triclosan | Wastewater treatment |
| Zinc pyrithione | Antifouling agent |
| Zineb (thiocarbamate) | Disinfection of industrial water systems; antifouling agent |

As mentioned, antifoulants are coatings containing toxic compounds that can be applied to the hull of a vessel to prevent the growth of organisms on the submerged sections of a vessel. The movement of water against the hull often activates the biocide in the coating. Laughton *et al.* (1992) suggested that increasing the amount and toxicity of antifoulant coatings and applying them to the inside of the ballast tank could kill organisms in ballast water. However, the use of poisonous wall coatings has been found by some researchers to be inappropriate for the inside of ballast tanks (Carlton *et al*., 1995). The New York State Division of Fish and Wildlife's Bureau of Habitat completed an assessment of two antifouling paints, ZO® and EP 2000®, both of which contain the active ingredient zinc pyrithione/zinc omadine. This assessment associated these paints with acute risks to freshwater vertebrates and freshwater and estuarine/marine invertebrates, as well as chronic risks to freshwater and estuarine/marine fish and invertebrates (NYS DEC Letter, September 15, 2003). Arends *et al.* (2001) found that the application of antifouling agents (e.g., organotins) to the inside of a ballast tank may not be effective due to a

reduced leaching rate (the water motion against the sides of the tank would be insufficient to activate the biocide) and a limited effectiveness on benthic organisms, which adhere to surfaces. Additionally, some chemicals, like tri(butyl) tin (TBT) and their residues, would be discharged with the ballast water and are not considered environmentally acceptable. Thus, the application of antifouling coatings to the inside of ballast tanks is not considered a proven method of ballast water treatment.

A number of other biocides that are described in the literature have not found wide application for controlling the growth of organisms. For example, a combination of copper and chloramines have been used to inactivate *Escherichia coli* and MS-2 coliphage (Straub *et al.*, 1995). Ferrate has been used to inactivate the f2 virus and coliforms in sewage effluent (Haas and Gould, 1980). Sodium azide is ineffective at removing dinoflagellate cysts at doses up to 500 milligrams per liter (mg/L) (Montani *et al.*, 1995). However, with respect to other organisms and species, very limited research data are available for these chemicals.

As previously indicated, only a few (chlorine, chlorine dioxide, glutaraldehyde, hydrogen peroxide, ozone, bromine, SeaKleen®) of the 32 biocides or biocide groups identified have been investigated for ballast water treatment to date[1]. The majority of biocides identified have been primarily used for industrial and drinking water treatment. Therefore, information on each specific evaluation criterion of this study is not readily available for these biocides/biocide groups. For example, while information regarding efficacy on target organisms was often available, information regarding its stability in the marine environment was lacking. On-going and future research in this area is expected to provide more information.

### 3.2 Biocide Modes of Action and Efficacy

Biocides may act through any of several modes of organism inactivation (Chattopadhyay *et al.*, 2002). These include (i) disruption of membrane, envelope, or capsid lipid or protein constituents; (ii) blockage of receptor-ligand interactions essential for infectivity; (iii) inhibition of replication of pathogens; (iv) alteration of the environment and reduction of susceptibility of infection; and, (v) enhancement of the local immune responses. In addition to the mode of action, there are many other factors that influence the efficacy of biocides on microorganisms and other aquatic species. These factors include the biocide's chemical properties, treatment process, the size and characteristics of the organism, biocide concentration, dosage and contact time, and water quality (e.g., salinity, pH, temperature, oxygen content). A comparison of the efficacy of selected biocides on selected microorganisms (bacteria, viruses, and bacterial spores) is shown in Table 3-2. The modes of action for all of the biocides evaluated were not identified, thus Table 3-2 provides a representative set. The shape of the symbol represents the type of microorganism, while the degree of shading provides a measure of the susceptibility of the microorganism class to the biocide.

[1] Additional potential biocides (e.g., hydroxyl radicals generated through electrochemical processes, oxygen stripping with pH changes, ferrate ions, and menadione nicotinamide bisulfate (MNB)) described during the 2nd International Conference and Exhibition on Ballast Water Management, 19-21 May 2004, Singapore are not evaluated in this report due to delivery schedule

**Table 3-2. Effects and Mode of Action of Selected Biocides on Microorganisms.**

| Biocide | Type of Microorganism: Vegetative bacteria (gram positive) | Vegetative bacteria (gram negative) | Mycobacteria (gram positive) | Fungi | Viruses | Bacterial Spores | Mode of Action |
|---|---|---|---|---|---|---|---|
| **Oxidizing** | | | | | | | |
| ***Halogen containing compounds*** | | | | | | | |
| Chloramines | Susceptible | Susceptible | Susceptible at high concentrations | Susceptible at high concentrations | Susceptible at high concentrations | Susceptible at high concentrations | Oxidizer of biological molecules (e.g., proteins, nucleic acids). |
| Iodine Compounds | Susceptible | Susceptible | Susceptible | Susceptible | Susceptible | Susceptible | Attacks N-H and S-S/S-H protein bonds. |
| Sodium hypochlorite | Susceptible | Susceptible | Susceptible | Susceptible | Susceptible | Susceptible | Similar to chloramines but more active. |
| ***Non-halogen containing compounds*** | | | | | | | |
| Hydrogen peroxide | Susceptible | Susceptible | Susceptible at high concentrations | Somewhat susceptible | Somewhat susceptible | Susceptible at high concentrations | Generates hydroxyl free radicals, which attack biological molecules. |
| **Non-oxidizing** | | | | | | | |
| Cationic surfactants | Susceptible | Somewhat susceptible | Resistant | Susceptible | Somewhat susceptible | Resistant | Affects proteins metabolic reactions, cell permeability, etc. |
| Formalin (37% formaldehyde) | Susceptible | Susceptible | Somewhat susceptible | Susceptible | Susceptible | Somewhat susceptible | Affects the cell wall and denatures amino proteins. |
| Glutaraldehyde | Susceptible | Susceptible | Susceptible | Susceptible | Susceptible | Susceptible | Affects proteins (e.g., enzymes, transport of nutrients, cell wall, etc.) |
| Peraclean® (peracetic acid) | Susceptible | Susceptible | Susceptible | Susceptible | Susceptible | Susceptible | Potent oxidizer |
| Phenol | Susceptible | Susceptible | Somewhat susceptible | Susceptible | Somewhat susceptible | Resistant | Combines with and denatures proteins. |

= Resistant   = Somewhat susceptible   = Susceptible at high concentrations   = Susceptible

Biocides exert inactivation or inhibitory effects by interacting with one or more targets in the microbial cells (Figure 3-1). Though the effect of biocides has not been established for many invertebrates, it is well known for fish. For example, chloramine passes through the gills of fish and enters the blood stream, where it reacts with hemoglobin (responsible for carrying oxygen in the blood) to form methemoglobin. Fathead minnows (*Pimephales primelas*) that are exposed to one part per million (ppm) monochloramine as chlorine have about thirty percent of their hemoglobin converted into methemoglobin (Grothe and Eaton, 1975). The fish then suffer from anoxia (low oxygen in their tissues) due to the loss of hemoglobin.

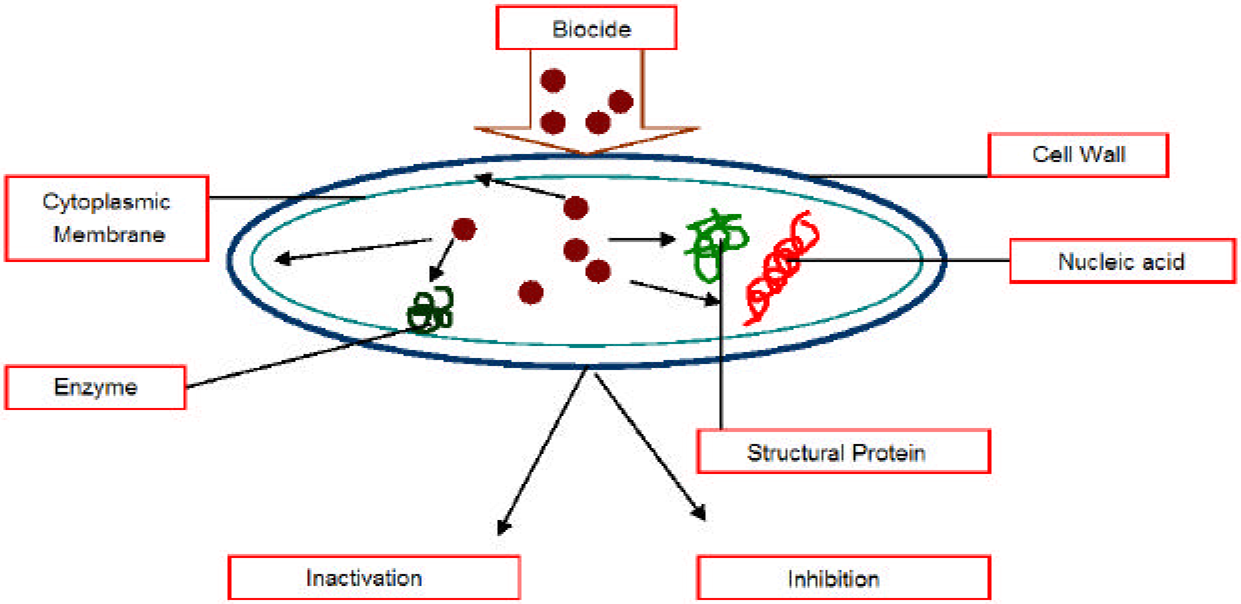



**Figure 3-1. Target Sites of Biocides in Microbial Cells.**
(modified after Bitton, 1999)

Biocides may be used to eliminate aquatic organisms in either a primary (without pretreatment) or a secondary treatment approach. The secondary treatment approach requires initial removal of interfering compounds and materials prior to the biocide being applied. Many believe that chemical treatment of ballast water cannot be a stand-alone treatment because of the high dosages required to kill larger organisms (Glosten-Herbert-Hyde Marine, 2002). However, a higher kill or removal rate may be accomplished when the biocide is applied as a secondary or tertiary treatment technique, such as application after filtration.

## 4.0 Comparison of Biocides to Evaluation Criteria

Nine criteria were developed to characterize the biocides (Section 2.1). Two of these, the physical characteristics and mode of action, were considered in Sections 3.1 and 3.2, respectively. An assessment of the biocides against the remaining characterization criteria is provided in this section. This assessment serves to: 1) compare the biocides; 2) qualitatively rate the biocides according to their potential usefulness as a ballast water treatment; and 3) illustrate those areas requiring further investigation. No attempt has been made to weigh the relative importance of the criteria, so arithmetic manipulation of the ratings should not be done. General information on biocide characteristics is presented in Table 3-3. Detailed information on the characteristics of each of the biocides can be found in the fact sheets in Appendix B.

**Table 3-3. General Characteristics of Biocides.**

| Biocide | General Characteristics |
|---|---|
| **Metal** | |
| Copper (ionic or salts)<br>Silver (ionic or salts) | • Limited applications of metal ions or salts (e.g., copper sulfate for the control of algal blooms in lakes and reservoirs).<br>• Not generally used due to human toxicity risk. |
| **Oxidizing** | |
| ***Halogen containing compounds*** | |
| Bromine<br>Chloramines<br>Chlorine<br>Chlorine Dioxide<br>Iodine<br>Sodium chlorite | • Provide wide germicidal activity but are corrosive.<br>• Not effective as sporocidal agents.<br>• Limited activity in the presence of organic matter.<br>• Residuals remain in water after treatment, low toxicity.<br>• Low cost but require frequent applications. |
| ***Non-halogen containing compounds*** | |
| Hydrogen peroxide<br>Ozone<br>Potassium Permanganate | • Moderate to wide germicidal activity, not sporocidal.<br>• Rendered ineffective in the presence of organic matter.<br>• Ozone requires very little contact time.<br>• Moderately corrosive, limited toxicity.<br>• Some residuals remain in water after treatment. |
| **Non-oxidizing** | |
| ***Acids*** | |
| Peraclean® (peracetic acid) | • Effective disinfectant with no known toxic residual.<br>• More potent than hydrogen peroxide.<br>• Rapidly active at low concentrations against a wide range of microorganisms.<br>• High bactericidal and virucidal effects.<br>• Corrosive and toxic at high concentrations.<br>• Highly efficient in presence of organic matter.<br>• Moderately expensive. |
| ***Aldehydes*** | |
| Formaldehyde<br>Glutaraldehyde | • Wide germicidal, sporocidal and fungicidal activity.<br>• Slight to moderate efficiency in presence of organic matter.<br>• Some residuals remain in water after treatment.<br>• Moderately toxic.<br>• Moderately expensive. |

**Table 3-3. General Characteristics of Biocides (cont'd).**

| Biocide | General Characteristics |
|---|---|
| ***Amines and halogenated amides*** | |
| Dibromonitrilopropionamide (DBNPA) | • Microbiocide<br>• White or pale yellow crystalline powder |
| Mexel® 432 (fatty amines) | • Toxic to fish and mollusks, low mammalian toxicity.<br>• Rapid degradation in the environment. |
| ***Heterocyclic ketones*** | |
| Polyhexamethylene biguanide (PHMB) | • Effective against bacteria and fungi, particularly pseudomonads. |
| Sea-Nine® (isothiazolone) | • Proposed as alternative to organotin compounds.<br>• Toxic to bacteria, diatoms, algae and barnacles. |
| ***Others*** | |
| 2-thiocyanomethylthiobenzothiazole (TCMTB) | • Proposed as alternative to organotin compounds. |
| Benzalkonium chloride | • Corrosive, toxic; can cause burns.<br>• May act as a mutagen.<br>• Incompatible with strong oxidizers and moisture. |
| Cationic surfactants (example: $C_{16}$-alkyltrimethylammonium chloride) | • Bactericide, virucide, and fungicide.<br>• Not sporocidal, limited germicidal capacity.<br>• Organic matter and salts cause reduced efficacy.<br>• Non-irritating, non-corrosive and low toxicity.<br>• Residual surfactant concentration dictates extent of recontamination.<br>• Low cost. |
| Chlorothalonil | • Proposed as alternative to organotin compounds. |
| Dichlofluanid | • Proposed as alternative to organotin compounds. |
| Dowicil® 75 N-(3-chloroallyl)hexaminium chloride) | • Slightly toxic to fish and aquatic invertebrates.<br>• Not persistent and degrades rapidly under acidic conditions. |
| Ethylene oxide | • Low to moderate aquatic toxicity.<br>• Non-persistent in the environment.<br>• Does not adsorb to sediments. |
| Grotan® (Hexahydro-1,3,5-tris(hydroxyethyl)-s-triazine) | • Broad spectrum bactericide, effective fungicide<br>• Protects from corrosion. |
| Irgarol® 1051 (2-methylthio-4-tert-butylamino-6-cyclo-propylamino-s-triazine) | • Proposed as alternative to organotin compounds. |
| Phenol | • Wide germicidal range, not sporocidal.<br>• Low toxicity and low corrosivity.<br>• Little or no residuals remain in water after treatment.<br>• Low to moderate cost. |

**Table 3-3. General Characteristics of Biocides (cont'd).**

| Biocide | General Characteristics |
|---|---|
| ***Others*** | |
| SeaKleen® (Vitamin K) | • Toxic to a broad spectrum of marine and freshwater organisms (fish larvae and eggs, planktonic crustaceans, bivalve larvae, *Vibrio* bacteria, and dinoflagellates). |
| Triclosan | • White crystalline powder<br>• Broad spectrum bactericide.<br>• Stable and incompatible with strong oxidizing agents. |
| Zinc pyrithione | • Proposed as alternative to organotin compounds. |
| Zineb (thiocarbamates) | • Insecticide, herbicide, and fungicide. |

A similar type of qualitative assessment was conducted by Greenman *et al.* (1997) (Table 4-1). These authors compared how a variety of biocides (chlorine, hydrogen peroxide, ozone, organic biocides, and coagulants) performed in the removal or inactivation of selected organisms. In addition, the modification of environmental conditions (pH adjustment, deoxygenation, and salinity adjustment) were ranked for biocidal capability. The first eight columns in Table 4-1 compare the removal/inactivation performance of the biocide on several species groups, as described by Greenwood *et al*. (1997). The ratings used in these eight columns (i.e., "***" = good; "**" = fair; "*" = poor) correspond to the efficacy of the biocide in removing or inactivating the organism in question. The next seven columns rate the biocides or treatment processes with respect to stage of development, reliability of operation, suitability for installation on new ships, suitability for land-based installation, occupational health and safety, and environmental acceptability. These factors were qualitatively rated as good, fair, and poor, as described above. An additional five performance characteristics (space requirements, energy consumption, monitoring requirements, capital cost, and operating cost) were evaluated with "high," "medium," and "low" ratings. Due to limited information on some biocides and their evaluation criteria, the authors also indicated uncertainty due to literature data gaps.

A similar comparison was performed on the 32 biocides identified under this study. The comparisons are provided against each evaluation criterion identified in Section 2.1.

### 4.1 Efficacy on Target Organisms

The efficacy of the biocides against nine major classes of organisms (viruses, bacteria, protozoa, fungi, zooplankton, algae, seaweeds, invertebrates, and fish) (National Water Quality Management Strategy, 2000) was evaluated. These nine organism classes characterize the expected taxa that would be encountered in marine or freshwater environments. According to the U.S. EPA's ECOTOX Database, a biocide can have numerous types of effects on aquatic organisms. These effects include direct mortality (which corresponds to the acute toxicity rating), bioaccumulation of the biocide in tissues, developmental disruptions, alteration of enzymatic activity, changes in feeding behavior and mobility, and reproductive system damage. A relative rating of the biocide's efficacy on the target organism was developed to provide a qualitative effectiveness assessment across biocides.

**Table 4-1. Comparison of Biocide Treatments and Their Performances.**

(after Greenman *et al.*, 1997)

| Biocides/ Treatment | Criteria for Comparison | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Performance (Removal/Inactivation) | | | | | | | | | | | | | | | | | | | |
| | Viruses | Bacteria | Protozoa[a] | Fungi[a] | Algae[a] | Seaweeds[a] | Invertebrates | Fish (Juvenile Larvae) | Stage of Development | Reliability of Operation | Suitability for Installation on New Ship | Suitability for Land-Based Installation | Suitability for Port-Based Installation | Occupational Health and Safety | Environmental Acceptability | Space Requirements | Energy Consumption | Monitoring Requirements | Capital Cost | Operating Cost |
| **Chlorine** | ** | *** | * | ** | * | * | * | *** | *** | *** | ** | *** | ** | * | * | ooo | ooo | oo | ooo | o(o) |
| **Hydrogen peroxide** | ** | *** | - | - | * | - | - | *** | *** | *** | ** | *** | ** | * | ** | ooo | ooo | oo | ooo | o |
| **Ozone** | *** | *** | ** | - | - | - | - | *** | *** | *** | * | *** | ** | ** | ** | oo | oo | oo | o | oo |
| **Organic biocides** | ** | *** | - | - | * | - | * | ** | ** | ** | ** | *** | ** | * | * | ooo | ooo | oo | ooo | o |
| **Coagulants** | * | * | - | - | - | - | - | - | *** | *** | ** | *** | *** | ** | *** | ooo | ooo | oo | ooo | oo |
| **pH adjustment** | ** | ** | - | - | * | - | - | ** | *** | *** | * | *** | ** | ** | ** | ooo | ooo | oo | ooo | oo |
| **Deoxygenation** | * | ** | * | * | * | * | - | - | *** | *** | ** | *** | ** | ** | ** | ooo | ooo | oo | ooo | oo |
| **Salinity adjustment** | * | - | - | - | * | - | - | ** | ** | ** | * | ** | * | *** | ** | ooo | oo | oo | ooo | o |

*** Good
** Fair
* Poor
o High
oo Medium
ooo Low
- Uncertain
[a] Performance rating based on cyst or spore usage

For this qualitative assessment, biocide effectiveness does not consider the conditions under which the biocide was tested; rather, the evaluation only considers whether the outcome of the study resulted in the desired effect. The qualitative ranking system is described below:

- A biocide was considered good and designated with a “1” if the $LC_{50}$ (i.e., the biocide concentration that is lethal to 50 percent of the tested organisms) was determined to be 1,000 micrograms per liter (μg/L) or less, if the $EC_{50}$ (i.e., the effective biocide concentration at which 50 percent of the tested organisms are impacted) included mortality of the organism as an impact, or if the reviewed literature designated the biocide as “effective.”
- A biocide was considered fair and designated with a “2” if the $LC_{50}$ was between 1,000 and 100,000 μg/L or the $EC_{50}$ reported endpoints other than mortality, such as inhibition of growth or biochemistry, intoxication, etc.
- A biocide was considered poor and designated with a “3” if the $LC_{50}$ was reported as greater than 100,000 μg/L or if the literature reported no effects observed or stated that the biocide was ineffective against that particular organism.

Table 4-2 shows which biocides were effective on the various target organism classes and also indicates the degree of effectiveness these biocides had on each organism class.

**Table 4-2. Efficacy of Biocides on Target Organisms.**

| **Biocide** | **Efficacy on Target Organisms** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Viruses** | **Bacteria** | **Protozoa** | **Fungi** | **Zoo-plankton** | **Algae** | **Seaweeds** | **Inverte-brates** | **Fish** |
| **Metal** | | | | | | | | | |
| Copper (ionic or salts) | - | - | - | 2 | 1 | 1-2 | 2 | 1-2 | 2 |
| Silver (ionic or salts) | - | - | - | 2 | 1-2 | 1-2 | 1-2 | 1-2 | 1-2 |
| **Oxidizing** | | | | | | | | | |
| ***Halogen containing compounds*** | | | | | | | | | |
| Bromine | - | 1 | - | - | 2 | - | - | 1-2 | 1 |
| Chloramines | 3 | 2 | 3 | 3 | - | - | - | 2 | - |
| Chlorine | 2 | 1 | 1 | 2 | 1 | 1-2 | 2 | 1-2 | 1 |
| Chlorine Dioxide | 2 | 1 | - | 2 | 2 | 2 | - | 1-3 | 1-3 |
| Iodine | 1 | 1 | - | 1 | 1 | - | - | - | 1-2 |
| Sodium chlorite | - | - | - | 2 | 1 | 2 | - | 1-2 | 3 |
| ***Non-halogen containing compounds*** | | | | | | | | | |
| Hydrogen peroxide | 2 | 1 | - | 1 | 1-2 | 1-2 | - | 1-2 | 2-3 |
| Ozone | 2 | 1 | 2 | - | - | - | - | 1-2 | 1-2 |
| Potassium Permanganate | 3 | 3 | 3 | 2 | 1 | 1-2 | - | 1-2 | 1-2 |
| **Non-oxidizing** | | | | | | | | | |
| ***Acids*** | | | | | | | | | |
| Peraclean® (peracetic acid) | 2 | 3 | 1 | 2 | 2 | - | - | - | 1-2 |

1 = good
2 = fair
3 = poor
- = information not available in the reviewed literature

Table 4-2. Efficacy of Biocides on Target Organisms (cont'd).

| Biocide | Efficacy on Target Organisms | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Viruses | Bacteria | Protozoa | Fungi | Zoo-plankton | Algae | Seaweeds | Inverte-brates | Fish |
| ***Aldehydes*** | | | | | | | | | |
| Formaldehyde | - | - | - | 1-2 | 1-3 | 1-2 | - | 1-3 | 1-3 |
| Glutaraldehyde | 1 | 1 | - | 2 | 2 | 1 | - | 1-2 | 2 |
| ***Amines and halogenated amides*** | | | | | | | | | |
| Dibromonitrilopropionamide (DBNPA) | - | - | - | - | 1 | 1 | - | 2 | 2 |
| Mexel® 432 (fatty amines) | - | 2 | - | - | - | 2 | - | 1 | 2 |
| ***Heterocyclic ketones*** | | | | | | | | | |
| Polyhexamethylene biguanide (PHMB) | - | 1 | - | 1 | 2 | - | - | 1-2 | 2 |
| Sea-Nine® (isothiazolone) | 3 | 3 | - | 3 | - | 1-2 | 1-2 | 1-2 | - |
| ***Others*** | | | | | | | | | |
| 2-thiocyanomethylthio benzothiazole (TCMTB) | - | - | - | - | 1-2 | - | - | 1-2 | 1 |
| Benzalkonium chloride | - | - | - | - | 1 | 2 | - | 1-2 | 1-2 |
| Cationic surfactants (example: $C_{16}$-alkyltrimethylammonium chloride) | 2 | 2-3 | - | 1 | 2 | 2 | - | 2 | 2 |
| Chlorothalonil | - | - | - | 1 | 1-2 | 2 | - | 1-2 | 1 |
| Dichlofluanid | - | - | - | 1 | - | - | - | 1-2 | 1 |
| Dowicil® 75 (N-(3-chloroallyl)hexaminium chloride) | - | - | - | - | 1-2 | - | - | 2-3 | 2 |
| Ethylene oxide | - | - | - | - | - | - | - | 3 | 3 |
| Grotan® (Hexahydro-1,3,5-tris(hydroxyethyl)-s-triazine) | - | 1 | - | 1 | - | - | - | - | - |
| Irgarol® 1051 (2-methylthio-4-tert-butylamino-6-cyclo-propylamino-s-triazine) | - | - | - | - | 2 | 2 | 2 | 2 | 1-2 |
| Phenol | 2 | 2-3 | - | 2 | 2 | 2 | 2-3 | 1-2 | 1-2 |
| SeaKleen® (Vitamin K) | 1 | 1 | 1 | - | 1 | 1 | - | 1 | 1 |
| Triclosan | - | 1 | - | - | 2 | - | - | - | 1 |
| Zinc pyrithione | - | 1 | - | 1 | - | - | - | 2 | 2 |
| Zineb (thiocarbamate) | - | - | - | 1 | 2 | 2 | - | 2-3 | 1-2 |

1 = good
2 = fair
3 = poor
- = information not available in the reviewed literature

Of the 32 biocides evaluated, eight of them demonstrated "fair" to "good" biocidal activity against a broad spectrum of organisms (chlorine, chlorine dioxide, hydrogen peroxide, glutaraldehyde, Peraclean®, SeaKleen®, phenol, and cationic surfactants (such as $C_{16}$-alkyltrimethylammonium chloride)) (Table 4-2). However, chlorine and hydrogen peroxide did not demonstrate significant efficacy against algae. Twenty-two biocides demonstrated "fair" to "good" biocidal activity against a smaller spectrum of target organisms, although information in the literature regarding effectiveness against each type of organisms was lacking. Of these 22 biocides, copper, iodine, sodium chlorite, formaldehyde, DBNPA, TCMTB, benzalkonium chloride, Irgarol®, and Dowicil 75® demonstrated good biocidal activity against zooplankton or phytoplankton (i.e., algae) or both.

Two biocides received "fair" to "poor" ratings: Sea-Nine® and potassium permanganate (Table 4-2). Sea-Nine® demonstrated "fair" to "good" biocidal activity against algae, seaweeds, and invertebrates, but was not effective against fungi, bacteria, and viruses. Similarly, potassium permanganate is effective for all organisms studied except viruses, bacteria, and protozoa.

The literature suggests that combining two or more biocides may allow for higher efficacy than using one biocide alone. In theory, biocides used in combination may address an organism's resistance to a particular substance or the weak or sub-lethal impacts of a single biocide. Biocidal combinations may be applied simultaneously or sequentially. The order of application can be manipulated to determine whether the impacts on the target organism(s) are greater when the single biocide is used, when the biocides are combined, or in a different permutation. For example, simultaneous application of ozone and chlorine dioxide to inactivate poliovirus type 1 was found more effective than the application of individual biocides sequentially (Wickramanayake, 1990). The order in which biocides used in combination are applied can be significant. For example, adding chlorine oxide after ozonation has been found to be more effective against poliovirus type 1 than when the treatments are applied in reverse order. Significant changes in virus inactivation results were also observed when the order of application of cationic surfactants (such as $C_{16}$-alkyltrimethylammonium chloride) and metals (minerals) was reversed (Chattopadhyay *et al*., 2002). This report does not evaluate combinations of biocides since the literature is limited.

## 4.2 Dosage Information

The effectiveness of a biocide depends on several factors including the concentration, duration of contact, and water quality variables (e.g., temperature, pH, turbidity, organic matter, dissolved solids). The type and dosage of a biocide need to be selected carefully because background conditions can vary substantially. This section provides information on percent organism inactivation or reduction after contact periods at defined biocide concentrations, pHs, and temperatures. Information was sought for each biocide across a broad spectrum of environmental variables for viruses, bacteria, fungi, and sub-cellular components. Different microorganisms and different strains of the same microorganism can exhibit variations in their inactivation percentages across a range of water conditions and application methods. The higher the chemical reactivity of a biocide, the greater its sensitivity to changes in temperature.

The Association Internatinale de la Savonnerie (AISE, 1997) has researched biocide dosage effectiveness on certain organism classes. The percentage of bacteria, fungi, viruses, and spores that remained active (i.e., log 5 kill) after application of the minimum amount of biocide are reported in Table 4-3. The results reported in this table indicate that sodium hypochlorite is relatively effective on the four studied organism classes. The other biocides have limited organism-specific effectiveness. The relative performance of six oxidizing biocides on bacteria (*Escherichia coli*) and poliovirus type 1 is presented in Figure 4-1. This figure is based on the information summarized by Wickramanayake (1990). Chlorine, chlorine dioxide, and ozone appear to be more effective than the other three oxidizing biocides. However, the study conditions, such as biocide dose (0.05 – 2700 mg-min/L), pH (5.9 – 7.2), and temperature (0 ºC – 25 ºC), varied significantly during treatment processes, making direct comparison problematic.

**Table 4-3. Activity of Microorganisms after Application of Biocide.**

(AISE, 1997)

| Biocide | % Remaining Active | | | |
|---|---|---|---|---|
| | **Bacteria** | **Fungi** | **Viruses** | **Spores** |
| Formaldehyde | 1 | 1 | 2 | 8 |
| Glutaraldehyde | 2 | 0.5 | 2 | 2 |
| Phenol | 1.5 | 5 | 5 | Not effective |
| Surfactants (quaternary ammonium compounds) | 0.0033 | Not effective | >10 | Not effective |
| Hydrogen peroxide | 5 | 10 | NA | 10 |
| Chlorine (sodium hypochlorite) | 0.0005 | 0.01 | 0.001 | 0.005 |

NA = not available

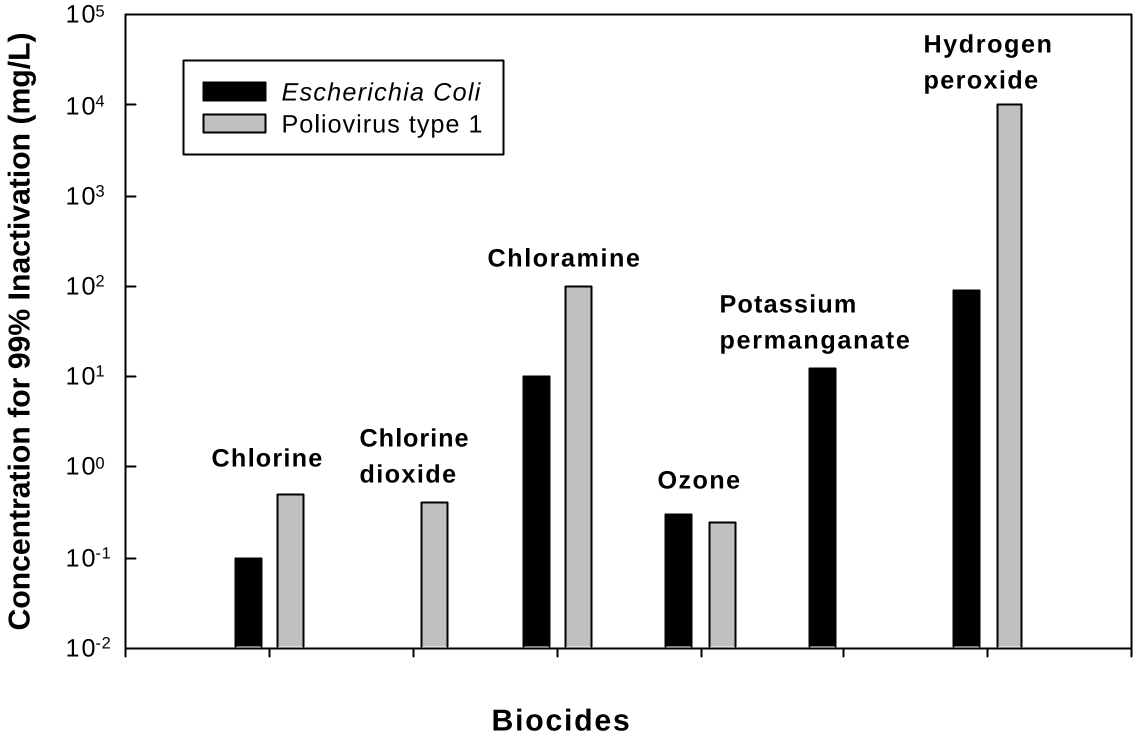



**Figure 4-1. Inactivation of *Escherichia coli* and Poliovirus type I by Selected Biocides.**
(based on the data summarized by Wickramanayake, 1990).

A complication of marine systems is that some biocides, like chloramine and chlorine, react with substances in seawater, forming other toxic chemical species. In the case of chlorine, these toxic species are often referred to as chlorine-produced oxidants (CPOs). For example, monochloramine is known to react with bromide in seawater over a period of hours to form bromochloramine (Br-NH-Cl) (Trofe *et al.,* 1980). If toxic species are detected, identifying the exact chemical substance causing toxicity is often difficult. Table 4-4 shows examples of the concentration of chlorine delivered by the chloramine or CPO that will kill half of the exposed individual organisms in 48 to 96 hours. This concentration is called the $LD_{50}$. In its ecological risk assessment of chloramine toxicity to marine invertebrates, Environment Canada determined the Estimated No-Effects Value (ENEV) to be 0.002 ppm-Cl for marine and estuarine environments (Wan *et al*., 2000). There is, however, substantial uncertainty in determining exactly which levels are acceptable and which are not, since there are so little data available.

**Table 4-4. Toxicity of Chloramine and CPOs to Marine Species.**

| Species | Concentration to kill half of the individuals in 48-96 h ($LD_{50}$) (ppm-Cl) | References |
|---|---|---|
| *Amphiporeia virginiana* (amphipod) | 0.57 | Wan *et al.*, 2000 |
| *Eohaustorius washingtonianus* (amphipod) | 0.63 | Wan *et al.*, 2000 |
| *Syngnathus fuscus* (pipe fish) | 0.27 | Bender *et al.*, 1977 |
| *Crassostrea virginica* larvae (oyster) | <0.005 | Bender *et al.*, 1977 |
| *Mercenaria mercenaria* larvae(clam) | <0.005 | Bender *et al.*, 1977 |
| *Acartia tonsa* (copepod) | <0.005 | Bender *et al.*, 1977 |
| Natural mixed phytoplankton | 0.1 | Bender *et al.*, 1977 |
| *Homarus americanus* larvae (lobster) | 0.3 | Capuzzo *et al.*, 1977 |
| *Homarus americanus* larvae (lobster) | 0.6 | Capuzzo *et al.*, 1976 |
| *Homarus americanus* larvae (lobster) | 0.05 ppm-Cl caused respiratory distress | Capuzzo *et al.*, 1976 |
| Juvenile killifish | >0.8 | Capuzzo *et al.*, 1977 |

The required dosage levels for 12 of the biocides evaluated in this report (Kim *et al*., 2002) to inactivate *Legionella* bacteria, the contact time, and the relevant water applications are shown in Table 4-5. Oxidizing biocides were found to be more effective in killing *Legionella* than non-oxidizing biocides. Among the non-oxidizing biocides tested, halogenated amides appear to be most effective followed by glutaraldehyde, polyhexamethylene biguanide (PHMB), and halogenated glycols.

The available information points to severe data gaps for biocide effectiveness across organism classes. Lacking standardized dosages, water quality conditions, and systematic inactivational kill data, it is difficult to provide robust comparison of the biocides. Regardless, the evidence at hand demonstrates that the type and dosage of a biocide must be selected carefully because background conditions can vary (e.g., pH, temperature, levels of organic and inorganic constituents, etc.).

**Table 4-5. Ranges of Reported Dosages of Biocides Against *Legionella* Bacteria.**
(modified after Kim *et al.*, 2002)

| Biocides | Typical dosage (mg/L) | Contact time | Application Target |
|---|---|---|---|
| **Metals** | | | |
| Copper ($Cu^{2+}$) | 0.1 – 1 | Hours to days | Drinking water |
| Silver ($Ag^{+}$) | 0.1 – 1 | Hours to days | Drinking water |
| **Oxidizing biocides** | | | |
| ***Halogen containing compounds*** | | | |
| Chlorine | 0.1 – 10 | Minutes to hours | Drinking water, Cooling water |
| Bromine | 0.1 – 10 | Minutes to hours | Cooling water |
| Chlorine dioxide | 1 – 10 | Minutes to hours | Drinking water |

**Table 4-5. Ranges of Reported Dosages of Biocides Against *Legionella* Bacteria. (cont'd.)**

| Biocides | Typical dosage (mg/L) | Contact time | Application Target |
|---|---|---|---|
| Monochloramine (chloramines) | 1 – 10 | Hours to days | Drinking water |
| ***Non-halogen containing compounds*** | | | |
| Ozone | 0.1 – 1 | Minutes to hours | Drinking water, Cooling water |
| Potassium permanganate | | Ineffective | |
| **Non-oxidizing biocides** | | | |
| **Heterocyclic ketones (isothiazolones)** | | | |
| Kathon (Sea-Nine®) | 1 –100 | Hours to days | Cooling water<br>Metal-working fluids |
| Polyhexamethylene biguanide (PHMB) | 1 – 100 | Hours to days | Cooling water<br>Metal-working fluids |
| Dibromonitrilopropionamide (DBNPA) | 1-100 | Hours to days | Cooling water<br>Metal-working fluids |
| Aldehydes (Glutaraldehyde) | 10-500 | Hours to days | Cooling water |

### 4.3 Inhibitors/Interferences to/with Biocide Reactivity

The efficacy of the biocides may vary depending on certain environmental conditions such as pH, alkalinity, total dissolved solids, and the amount of organic matter (including sediments and suspended particulate matter) present in the water to be treated. Dissolved solids refer to any minerals, salts, metals, cations, or anions dissolved in water. Total dissolved solids (TDS) are comprised of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and some small amounts of organic matter that are dissolved in water. Ballast water can have a wide range of pH and total dissolved solids values due to geographic, climatic, and water quality variations. A biocide's ability to treat organisms over a wide range of water quality conditions, for example, is important.

The pH of the water to be treated can impact the efficacy of the biocide in several ways. For example, hypochlorus acid (the biocidal oxidizing agent created when chlorine comes into contact with water) will ionize into the inactive hypochlorite ion as the water pH value increases, thereby rendering the biocide ineffective. A similar reaction occurs with bromine. The hypobromite ion (an ineffective biocide) will replace hypobromous acid (an effective biocide) as water pH levels rise. Dissolved solids in the water also affect biocidal properties of some materials. For example, in the presence of organics or inorganics in the water, potassium permanganate will be partially consumed in the oxidation of these dissolved substances. Adsorption to particles in the water can also have a negative effect on the efficacy of some biocides. Copper, for example, is a particle reactive chemical that tends to adsorb to sediments in the water column or on the bottom, making any biocidal reactions difficult.

A relative rating of the biocides with regard to biocide efficacy and pH, dissolved solids, and organic matter is provided in Table 4-6. A rating of "1" indicates that the biocide efficiency is not affected by that particular parameter, a "2" indicates that the biocide is somewhat affected, and a "3" indicates that the biocide is significantly affected by that parameter. Dashes indicate that the available information is insufficient to characterize the biocide. For instance, chlorine

dioxide has been assigned a “1” for all three environmental parameters, indicating that this biocide is effective over a wide range of pH values, does not react with dissolved solids, and does not adsorb to organic particulates. Conversely, the scoring for chlorine (“3”s for each parameter) reveals that this biocide is significantly affected by all three parameters such that it is only effective at small pH ranges, reacts with dissolved solids, and will adsorb to organic particulates.

**Table 4-6. Level of Inhibition/Interference with Biocide Effectiveness by pH, Total Dissolved Solids, and Organic Matter.**

| Biocides | Inhibitors/Interferences | | |
|---|---|---|---|
| | **pH Inhibition** | **Reactivity with Total Dissolved Solids** | **Adsorption to Particles or Organic Matter** |
| **Metal** | | | |
| Copper (ionic or salts) | 2 | 3 | 3 |
| Silver (ionic or salts) | - | 3 | 2 |
| **Oxidizing** | | | |
| ***Halogen containing compounds*** | | | |
| Bromine | 3 | - | 3 |
| Chloramines | 1 | - | 2 |
| Chlorine | 3 | 3 | 3 |
| Chlorine Dioxide | 1 | 1 | 1 |
| Iodine | - | - | - |
| Sodium chlorite | - | - | - |
| ***Non-halogen containing compounds*** | | | |
| Hydrogen peroxide | 3 | - | - |
| Ozone | 2 | - | 3 |
| Potassium Permanganate | 2 | 2 | 2 |
| **Non-oxidizing** | | | |
| ***Acids*** | | | |
| Peraclean® (peracetic acid) | - | - | 3 |
| ***Aldehydes*** | | | |
| Formaldehyde | 2 | - | - |
| Glutaraldehyde | 3 | 1 | 1 |
| ***Amines and halogenated amides*** | | | |
| Dibromonitrilopropionamide (DBNPA) | - | - | 2 |
| Mexel 432 (fatty amines) | - | - | - |

1 = not affected (if the table goes two pages, the legend should appear on both pages)
2 = somewhat affected
3 = significantly affected
- = information not available in the reviewed literature

**Table 4-6. Level of Inhibition/Interference with Biocide Effectiveness by pH, Total Dissolved Solids, and Organic Matter (cont'd).**

| Biocides | Inhibitors/Interferences | | |
|---|---|---|---|
| | pH Inhibition | Reactivity with Total Dissolved Solids | Adsorption to Particles or Organic Matter |
| ***Heterocyclic ketones*** | | | |
| Polyhexamethylene biguanide (PHMB) | 1 | - | - |
| Sea-Nine® (isothiazolone) | - | - | - |
| ***Others*** | | | |
| 2-thiocyanomethylthiobenzothiazole (TCMTB) | - | - | - |
| Benzalkonium chloride | - | - | - |
| Cationic surfactants (example: $C_{16}$-alkyltrimethylammonium chloride) | - | - | 1 |
| Chlorothalonil | - | - | - |
| Dichlofluanid | - | - | 2 |
| Dowicil® 75 (N-(3-chloroallyl)hexaminium chloride) | 1 | - | 3 |
| Ethylene oxide | 3 | - | 1 |
| Grotan® (Hexahydro-1,3,5-tris(hydroxyethyl)-s-triazine) | - | - | - |
| Irgarol® 1051 (2-methylthio-4-tert-butylamino-6-cyclo-propylamino-s-triazine) | - | - | 1 |
| Phenol | - | - | 3 |
| SeaKleen® (Vitamin K) | - | - | 1 |
| Triclosan | - | - | - |
| Zinc pyrithione | - | - | - |
| Zineb (thiocarbamate) | - | - | - |

1 = not affected (if the table goes two pages, the legend should appear on both pages)
2 = somewhat affected
3 = significantly affected
= information not available in the reviewed literature

Some chemicals are affected by the dissociation of acids at high pH. For example, Oemcke (1999) reports that bromine becomes about 20 percent less effective at a typical seawater pH of 8.2 because the hypobromite ion, which is a less effective disinfectant, forms as pH increases. Oemcke also indicates that ozone, chlorine dioxide, and chloramines are not affected by pH. Simpson *et al.* (1993) found that chlorine dioxide retains its biocidal effectiveness over a wide pH range. The alkalinity of the water can also affect the biocidal activity. According to Lubomudrov (1997), the biocidal activity of glutaraldehyde decreases with increasing alkalinity, as does chlorine (U.S. EPA, 1999). Biocides that are strongly influenced by pH include chlorine, hydrogen peroxide, potassium permanganate, glutaraldehyde, bromine, and ethylene oxide (Table 4-6). Those less affected or not affected by pH are chlorine dioxide, chloramines, copper,

ozone, Dowicil® 75, and polyhexamethylene biguanide (PHMB). Information on the impacts of pH values on the other biocides was not available in the reviewed literature.

The presence of dissolved solids in the water can impact the efficacy of a particular biocide through various reactions and changes in the speciation of the chemical (Table 4-6). The biocides that tend to react with dissolved solids include copper, silver, and chlorine. Those less affected or not affected at all by the presence of dissolved solids are chlorine dioxide, potassium permanganate, ozone, and glutaraldehyde. Information regarding reactivity with dissolved solids for the other 25 biocides was not available in the reviewed literature.

Biocides expected to adsorb to particles or react with organic matter in the water are also indicated in Table 4-6. Biocides having a strong affinity to adsorb are noted with a "3". These biocides include copper, chlorine, bromine, ozone, Peraclean®, Dowicil® 75, and phenol. Biocides with a moderate to weak affinity to adsorb include potassium permanganate, chloramines, dichlofluanid, and DBNPA. Biocides that would not adsorb or react with organic matter include chlorine dioxide, glutaraldehyde, SeaKleen®, cationic surfactants (such as $C_{16}$-alkyltrimethylammonium chloride), ethylene oxide, and Irgarol® 1051.

## 4.4 Degradation and Byproducts of the Biocide

The stability of a biocide in water depends on the properties of the biocide and the environmental conditions of the water (e.g., pH and temperature). The stability of a biocide can be defined in terms of degradation rates (i.e., half-life), or its recalcitrance (resistance to biodegradation) in the environment. In addition, stability can be defined by the biocide's propensity to react with other compounds to form byproducts and to experience hydrolysis (i.e., reaction with water). The generation of reaction byproducts is a concern as these byproducts should not produce more harm than the biocide itself, particularly if these byproducts would be released into harbor waters during deballasting operations. The rate of degradation of biocidal agents generally depends on the concentration applied and the concentration of suspended particles in the ballast tanks. The byproducts produced by a biocide and the associated degradation rates are two characteristics that may be regulated by state, federal, or international statute or convention.

Table 4-7 presents the relative rankings of toxic byproduct formation, recalcitrance, and regulatory concerns for each biocide. Ratings of "1", "2", or "3" were assigned to each of the biocides for each category. For the toxic byproduct formation rating, a score of "1" indicates that the biocide does not form toxic byproducts; a "2" indicates that the biocide may produce byproducts of low toxicity; and a "3" indicates that the byproducts produced are more toxic than the biocide itself. For the recalcitrance rating, a rank of "1" signifies that the biocide degrades quickly, usually within a one to two-day period; a "2" denotes that the biocide requires more than two days but less than one week to degrade; and, a "3" indicates that the biocide requires more than one week to degrade. For the regulatory concerns rating, a "1" indicates that there are no known regulations associated with the biocide or its degradative compound either in the aquatic environment or for storage or transportation; a "2" denotes that there are no environmental regulations associated with the biocide or its degradative compounds in the aquatic environment, but regulatory requirements (i.e., registration) are necessary for the use, transport, or storage; and a "3" signifies that the biocide or its degradation byproducts are strictly governed by regulations with regard to its presence in water and regulatory requirements (i.e.,

registration) are necessary for use, transport, or storage. Dashes indicate that the available information is insufficient to characterize the biocide. The regulatory concerns for the biocides are further discussed in Section 4.8.

**Table 4-7. Environmental Concerns on Biocide Use.**

| Biocides | Environmental Concerns | | |
|---|---|---|---|
| | **Toxic Byproduct Formation** | **Recalcitrant** | **Regulatory Concerns** |
| **Metals** | | | |
| Copper (ionic or salts) | 1 | 2 | 3 |
| Silver (ionic or salts) | 1 | 2 | 3 |
| **Oxidizing** | | | |
| ***Compounds containing halogen*** | | | |
| Chlorine | 3 | 2 | 3 |
| Bromine | 3 | - | 1 |
| Iodine | 3 | - | 1 |
| Chlorine Dioxide | 2 | 2 | 2 |
| Sodium chlorite | 3 | 2 | 3 |
| Chloramines | 3 | 2 | - |
| ***Compounds not containing halogen*** | | | |
| Hydrogen peroxide | 2 | 1 | 2 |
| Ozone | 2 | 1 | 3 |
| Potassium Permanganate | 1 | 2 | 2 |
| **Non-Oxidizing** | | | |
| ***Acids*** | | | |
| Peraclean® (peracetic acid) | - | - | 2 |
| ***Aldehydes*** | | | |
| Formaldehyde | 1 | 1 | 3 |
| Glutaraldehyde | 1 | 1 | 1 |
| ***Amines and halogenated amides*** | | | |
| Dibromonitrilopropionamide (DBNPA) | - | 1 | 1 |
| Mexel® 432 (fatty amines) | 1 | 1 | 1 |
| ***Heterocyclic ketones*** | | | |
| Polyhexamethylene biguanide (PHMB) | - | - | 2 |
| Sea-Nine® (isothiazolone) | 1-2 | 1 | - |
| **Others** | | | |
| 2-thiocyanomethylthio benzothiazole (TCMTB) | - | - | 1-2 |
| Benzalkonium chloride | - | - | 1 |
| Cationic surfactants (example: $C_{16}$-alkyltrimethylammonium chloride) | - | 2 | 2 |
| Chlorothalonil | - | 1 | 2 |

- = information not available in the reviewed literature

**Table 4-7. Environmental Concerns on Biocide Use (cont'd).**

| Biocides | Environmental Concerns | | |
|---|---|---|---|
| | Toxic Byproduct Formation | Recalcitrant | Regulatory Concerns |
| Dichlofluanid | - | 1 | 1 |
| Dowicil® 75 (N-(3-chloroallyl)hexaminium chloride) | 3 | 1 | 2 |
| Ethylene oxide | 2 | 1 | 3 |
| Grotan® (Hexahydro-1,3,5-tris(hydroxyethyl)-s-triazine) | - | - | 2 |
| Irgarol® 1051 (2-methylthio-4-tert-butylamino-6-cyclo-propylamino-s-triazine) | - | 3 | 1 |
| Phenol | 1 | 1 | 3 |
| SeaKleen® (Vitamin K) | 1 | 1 | 1 |
| Triclosan | 1 | 1 | 1-2 |
| Zinc pyrithione | - | 1 | - |
| Zineb (thiocarbamate) | - | - | 1 |

- = information not available in the reviewed literature

The formation of toxic byproducts depends on the environmental conditions of the water. For example, naturally occurring constituents such as bromide in sea water may readily react with chlorine to change the disinfection effect relative to those in freshwater (Oemcke, 1999). In addition, chlorine and bromine react with naturally occurring organic matter in the water to produce trihalomethanes (THM) such as chloroform. THMs are regulated under the United States' Clean Water Act; thus, consideration of environmental acceptability is required before these particular biocides could be approved for ballast water treatment. Ozone is known to react with the bromide ion present in sea water to form the byproducts bromoform and the bromate ion (Simpson *et. Al.*, 1993; Oemcke, 1999; Cooper *et. Al.*, 2002). Bhaskar and Pederson (2003) found that reactions between some biocides and seawater could produce harmful byproducts that have not been extensively studied.

Toxic byproducts are formed from the application of chlorine, bromine, sodium chlorite, chloramines, and Dowicil® 75. Depending on existing environmental conditions, toxic byproducts may be associated with chlorine dioxide, ethylene oxide, ozone, hydrogen peroxide, and Sea-Nine®. Toxic byproducts are not associated with copper, silver, potassium permanganate, formaldehyde, glutaraldehyde, Mexel® 432, phenol, SeaKleen®, and triclosan. Information for the other 13 biocides was not available in the reviewed literature.

As presented in Table 4-7, compounds that are not recalcitrant and are described in the literature as disappearing quickly or have half-lives less than two days include hydrogen peroxide, ozone, formaldehyde, glutaraldehyde, Mexel® 432, DBNPA, Sea-Nine®, chlorothalonil, dichlofluanid, Dowicil® 75, ethylene oxide, phenol, zinc pyrithione, SeaKleen®, and triclosan. Cooper *et. Al.*, (2002) found that ozone catalytically decomposes in sea water with a half-life of five seconds and reverts to oxygen ($O_2$). Compounds that are somewhat recalcitrant (taking more than two days but less than one week to degrade) include copper, silver, chlorine, chlorine dioxide,

sodium chlorite, chloramines, potassium permanganate, and cationic surfactants (such as $C_{16}$-alkyltrimethylammonium chloride). Only Irgarol® 1051 was identified as highly recalcitrant, taking over one week to fully degrade. Information for the other eight compounds was not obtained from the reviewed literature.

Regulatory concerns (Table 4-7) are a major issue for copper, silver, chlorine, sodium chlorite, ozone, formaldehyde, ethylene oxide, and phenol. Some regulatory consideration must be given to the following biocides: chlorine dioxide, hydrogen peroxide, potassium permanganate, Peraclean®, PHMB, TCMTB, chlorothalonil, Dowicil® 75, zinc pyrithione, cationic surfactants (such as $C_{16}$-alkyltrimethylammonium chloride), and triclosan. Regulatory restrictions are not a concern for bromine, iodine, glutaraldehyde, Mexel® 432, DBNPA, benzalkonium chloride, dichlofluanid, Irgarol® 1051, SeaKleen®, and zineb.

### 4.5 Availability of the Biocide

To gather information on commercially available forms of biocides, vendors and manufacturers were contacted and marketing literature was reviewed. Biocide vendors were found to offer several forms of product material depending on the types of biocide sold. The information obtained indicated that some biocides could be shipped with few restrictions while others were more extensively regulated. Still others are too unstable to be shipped and would require on-site generation (i.e., on the vessel during transit). Ozone, monochloramine, and chlorine dioxide are examples of biocides that must be generated on-site. Table 4-8 summarizes commercially-available biocides and the forms in which they are available. This table also indicates whether a biocide is capable of being generated on-site.

Several forms of free chlorine including molecular chlorine (chlorine gas), liquid sodium hypochlorite, and granulated calcium hypochlorite are available. Biocides generally may be purchased in full strength or mixed solutions, solid, powdered, or crystalline form.

**Table 4-8. Forms of Commercially Available Biocides.**

| **Biocides** | **Commercially-Available Forms** | | | |
|---|---|---|---|---|
| | **Solid** | **Liquid** | **Gas** | **On-Site Generation** |
| **Metals** | | | | |
| Copper ions | X | | | X |
| Copper sulfate | X | X | | |
| Silver ions | | X | | X |
| **Oxidizing** | | | | |
| ***Halogen-containing compounds*** | | | | |
| Chlorine | | | X | |
| Bromine | | X | X | |
| Iodine | X | X | | |

X = the biocide is commercially available in that form or the biocide requires on-site generation
[1] dry media capable of releasing $ClO_2$ when activated with moisture or humidity.
[2] stabilized chlorine dioxide solutions or buffered sodium chlorite that must be reacted with an acid.
[3] unable to transport in this form due to instability.

**Table 4-8. Forms of Commercially Available Biocides (cont'd).**

| Biocides | Commercially-Available Forms | | | |
|---|---|---|---|---|
| | **Solid** | **Liquid** | **Gas** | **On-Site Generation** |
| Chlorine Dioxide | X[1] | X[2] | X[3] | X |
| Sodium chlorite | X | X | | |
| Chloramines | X | | | X |
| ***Non-halogen containing compounds*** | | | | |
| Hydrogen peroxide | X | X | | |
| Ozone | X | X | X[3] | X |
| Potassium Permanganate | X | X | | |
| **Non-Oxidizing** | | | | |
| ***Acids*** | | | | |
| Peraclean® (peracetic acid) | | X | | |
| ***Aldehydes*** | | | | |
| Formaldehyde | | X | X | |
| Glutaraldehyde | | X | | |
| ***Amines and halogenated amides*** | | | | |
| Mexel® 432 (fatty amines) | | X | | |
| Dibromonitrilopropionamide (DBNPA) | X | X | | |
| ***Heterocyclic ketones*** | | | | |
| Polyhexamethylene biguanide (PHMB) | X | X | | |
| Sea-Nine® (isothiazolone) | | X | | |
| **Others** | | | | |
| 2-thiocyanomethylthio benzothiazole (TCMTB) | | X | | |
| Benzalkonium chloride | X | X | | |
| Cationic surfactants (example: $C_{16}$-alkyltrimethylammonium chloride) | X | X | | |
| Chlorothalonil | X | | | |
| Dichlofluanid | | X | | |
| Dowicil® 75 (N-(3-chloroallyl)hexaminium chloride) | | X | | |
| **Others** | | | | |
| Ethylene oxide | | | X | |
| Grotan® (Hexahydro-1,3,5-tris(hydroxyethyl)-s-triazine) | | X | | |

X = the biocide is commercially available in that form or the biocide requires on-site generation
[1] dry media capable of releasing $ClO_2$ when activated with moisture or humidity.
[2] stabilized chlorine dioxide solutions or buffered sodium chlorite that must be reacted with an acid.
[3] unable to transport in this form due to instability.

**Table 4-8. Forms of Commercially Available Biocides (cont'd).**

| Biocides | Commercially-Available Forms | | | |
|---|---|---|---|---|
| | Solid | Liquid | Gas | On-Site Generation |
| Irgarol® 1051 (2-methylthio-4-tert-butylamino-6-cyclo-propylamino-s-triazine) | X | | | |
| Phenol | X | X | | |
| SeaKleen® (Vitamin K) | X | | | |
| Triclosan | X | X | | |
| Zinc pyrithione | X | | | |
| Zineb (thiocarbamate) | X | | | |

X = the biocide is commercially available in that form or the biocide requires on-site generation
[1] dry media capable of releasing $ClO_2$ when activated with moisture or humidity.
[2] stabilized chlorine dioxide solutions or buffered sodium chlorite that must be reacted with an acid.
3 unable to transport in this form due to instability.

## 4.6 Shipboard Considerations

The application of a biocide on board a ship may be constrained by several factors, including the size of the treatment system in relation to the size of the ship, the biocide's concentration, storage requirements, how the biocide is generated (if shipboard), biocide compatibility with the structural material of the ship, and the unit cost of application. A variety of approaches may be used to introduce biocides to ballast water depending on the physical and chemical properties of the biocide. For example, a liquid or aqueous biocidal solution could be administered by metered injection into ballast fill lines to ensure adequate mixing and proper application rate. Alternatively, solids (sparingly soluble or slow dissolution rate) or liquid chemical dosing packets can be added directly into the tanks. The chemical injection equipment is relatively inexpensive and requires few ship resources in terms of space and power. Further consideration for shipboard application can be found in Section 4.7. Table 4-9 provides an analysis of the biocides in terms of shipboard storage, compatibility, and generation.

The safe storage of sufficient quantities of a biocide is one of the major considerations in considering a shipboard treatment. For example, bromine has several safety-related concerns, including a requirement to keep it as cool as possible. In addition, the corrosive and poisonous nature of bromine demands that it be stowed clear of living quarters and separated from flammable solids, oxidizers, and radioactive materials. Hydrogen peroxide is another biocide with storage concerns, including its sensitivity to heat and light, both of which can lead to a reduced lifetime in the storage tanks. In the United States, the Department of Transportation regulates the storage and transportation of hazardous materials aboard vessels. The table of hazardous materials in 49 CFR 172.101 was used in rating shipboard storage requirements (DOT, 2002). The biocides rated "3" in Table 4-9 require storage away from living quarters, are extremely reactive with other materials, and can be highly flammable or poisonous to humans. A "2" was given to biocides that require certain conditions to maintain their shelf life but generally have moderate storage requirements. A "1" was assigned to biocides that had minimal or no storage concerns related to safety.

A biocide management system will generally be easier to install in new ships than retrofitting already existing vessels. Table 4-9 also presents rankings for the difficulty of installing a biocide management system on a vessel. This rating was based primarily on storage requirements, compatibility with the vessel's structural material, and safety considerations. A ranking of "1" in Table 4-9 indicates that the biocide management system is easily installed; a "2" signifies that shipboard installation may require additional storage and conveyance requirements; and, a "3" indicates that shipboard installation may entail considerable extra power requirements, size constraints, and safety considerations, and, therefore, would be relatively difficult to install.

The compatibility of the biocide with the ship's structural material proves important during storage and dosing but also while the biocide degrades within the ship's tanks. Corrosivity and reactivity were considered when rating a biocide's vessel compatibility in Table 4-9. Extremely corrosive materials were rated with a "3"; a "2" indicates a slightly acidic or alkaline material or a low-medium range oxidizer that requires care when storing/handling and may be slightly corrosive; and, a "1" indicates a biocide that would have no known adverse effects on the structural integrity of a vessel. Over long periods of time, biocides rated with a "2" or "3" may adversely impact the vessel's integrity.

Some biocides like ozone and chlorine dioxide must be generated on board the vessel because they cannot be safely stored. A dry form precursor of chlorine dioxide has been developed and, when activated with water or moisture, chlorine dioxide is released (Raytec Corp, 2004). When biocides are generated on board a vessel, additional maintenance checks of the generation equipment will be required. These maintenance requirements will need to be conducted in accordance with vendors' recommendations. In Table 4-9, a "1" was assigned if the requirements surrounding on board generation are minimal. When the potential exists for noxious fumes to form or off-gassing to occur during biocide generation, a "2" was assigned to the shipboard generation category. A "3" indicates intensive maintenance requirements for the generation equipment and the creation of hazardous conditions when pre-cursors are mixed to form a biocide.

The costs related to using biocide treatment vary and depend on several factors. Some of these factors include: ballast water characteristics, biocide market demand, ballast capacity, trip length, and size of ballast tanks and pumps (Oemcke, 1999). Other cost factors are related to the biocide and include what form it is in (solid, liquid, or gas), concentration, decay rate, and availability. Additional costs can be incurred from operating the treatment system including fuel consumption and maintenance (Rigby and Taylor, 2001). In an Australian study, cost estimates to treat ballast water with biocides ranged from \$0.24 - \$40.00/$m^3$ (Rigby, 2001). The costs of a biocide can vary according to supplier, biocide form, and dosage. The biocide form and dosage can, in turn, vary with safety and storage requirements. In Table 4-9, a ranking of "1" indicates that the biocide is relatively inexpensive to use; a "2" indicates that the biocide and any technology associated with it can have a moderate maintenance and unit cost; and a "3" signifies that the biocide and technology can have a high maintenance and unit cost. Dashes indicate that the available information is insufficient to characterize the biocide.

Table 4-9. Biocide Use with Regard to Shipboard Application.

| Biocide | Application | | | | |
|---|---|---|---|---|---|
| | Storage | Ship Installation Difficulty | Vessel Compatibility | Shipboard Generation | Costs |
| **Metals** | | | | | |
| Copper (ionic or salts) | 2 | 2 | - | 2 | 1 |
| Silver (ionic or salts) | 2 | 2 | - | 2 | 1 |
| **Oxidizing** | | | | | |
| ***Halogen containing compounds*** | | | | | |
| Bromine | 3 | 2-3 | 3 | - | 1 |
| Chloramines | - | 2 | 3 | 2 | 1 |
| Chlorine | 3 | 3 | 3 | - | 2 |
| Chlorine Dioxide | 2-3 | 2 | 3 | 3 | 2-3 |
| Iodine | 2 | 2 | 2 | - | 2 |
| Sodium Chlorite | 2 | 2 | 2 | - | 1 |
| ***Non-halogen containing compounds*** | | | | | |
| Hydrogen Peroxide | 2 | 2 | 3 | - | 2 |
| Ozone | - | 3 | 3 | 3 | 3 |
| Potassium Permanganate | 2 | 2 | 2 | - | - |
| **Non-oxidizing** | | | | | |
| ***Acids*** | | | | | |
| Peraclean® (peracetic acid) | 1 | 1 | 2 | - | 1 |
| ***Aldehydes*** | | | | | |
| Formaldehyde | 2 | 2 | 2 | - | 2 |
| Glutaraldehyde | 2 | 1 | 1 | - | 2 |
| ***Amines and halogenated amides*** | | | | | |
| Dibromonitrilopropionamide (DBNPA) | - | - | - | - | - |
| Mexel® 432 (fatty amines) | 1 | 1 | 1 | - | - |
| ***Heterocyclic ketones*** | | | | | |
| Polyhexamethylene Biguanide (PHMB) | - | - | - | - | - |
| Sea-Nine® (isothiazolone) | 2 | 2 | - | - | - |

Storage: 1 = minimal concerns in storing product; 2 = requirements for cool, dry, or ventilated area; 3 = "on deck only" requirements to keep clear of living quarters, poisonous, extremely reactive or flammable

Suitability for Installation: 1 = easily installed; 2 = additional biocide storage and conveyance requirements; 3 = power requirements, size constraints, and safety considerations may make installation difficult

Vessel Compatibility: 1 = no corrosive effects; 2 = low-medium level oxidizer or slightly corrosive; 3 = extremely corrosive

Generation: 1 = minimal requirements for generation; 2 = additional maintenance checks on equipment, potential for fumes or off-gassing; 3 = maintenance intensive, hazardous conditions while mixing

Cost Effectiveness: 1 = inexpensive; 2 = capital investment with moderate maintenance and biocide unit cost; 3 = high capital investment, high maintenance and biocide unit cost

**Table 4-9. Biocide Use with Regard to Shipboard Application (cont'd).**

| Biocide | Application | | | | |
|---|---|---|---|---|---|
| | Storage | Ship Installation Difficulty | Vessel Compatibility | Shipboard Generation | Costs |
| **Others** | | | | | |
| 2-thiocyanomethylthio benzothiazole (TCMTB) | - | - | - | - | - |
| Benzalkonium Chloride | - | - | - | - | - |
| Cationic surfactants (example: $C_{16}$-alkyltrimethylammonium chloride) | - | - | - | - | 2 |
| Chlorothalonil | 2 | - | - | - | - |
| Dichlofluanid | 1 | - | - | - | - |
| Dowicil® 75 | 1 | - | - | - | - |
| Ethylene Oxide | 2 | 2-3 | - | - | - |
| Grotan | 2 | 2 | - | - | - |
| Irgarol 1051 | - | - | - | - | - |
| Phenol | 2 | 2 | - | - | 2 |
| SeaKleen® (Vitamin K) | 1 | 1 | 1 | - | 1 |
| Triclosan | - | - | - | - | - |
| Zinc pyrithione | - | - | - | - | - |
| Zineb (thiocarbamate) | - | - | - | - | - |

Storage: 1 = minimal concerns in storing product; 2 = requirements for cool, dry, or ventilated area; 3 = "on deck only" requirements to keep clear of living quarters, poisonous, extremely reactive or flammable
Suitability for Installation: 1 = easily installed; 2 = additional biocide storage and conveyance requirements; 3 = power requirements, size constraints, and safety considerations may make installation difficult
Vessel Compatibility: 1 = no corrosive effects; 2 = low-medium level oxidizer or slightly corrosive; 3 = extremely corrosive
Generation: 1 = minimal requirements for generation; 2 = additional maintenance checks on equipment, potential for fumes or off-gassing; 3 = maintenance intensive, hazardous conditions while mixing
Cost Effectiveness: 1 = inexpensive; 2 = capital investment with moderate maintenance and biocide unit cost; 3 = high capital investment, high maintenance and biocide unit cost

### 4.7 Personnel Safety

Safety is a critical aspect of all vessel operations, particularly in terms of biocide usage. A ship must be recognized as an unstable platform subject to a variety of weather conditions and other operational problems. The safe storage and handling of chemicals under these conditions can be quite different from land-based operations (Rigby and Taylor, 2001). In addition to safety concerns, consideration must also be given to the level of training required to use the biocide. Table 4-10 presents the various safety concerns, according to Material Safety Data Sheets (MSDSs), of the investigated biocides. "X" indicates there is an associated safety concern for the category.

In determining a biocide's ease of use, any special training requirements must be considered as well as the level of difficulty expected in obtaining or generating the biocide. Generally, biocide

usage is not complex. Training for personnel would be required for compounds that require on board generation (e.g., chlorine dioxide). Based on the literature and information reviewed, no special training is required for the use of the following biocides: potassium permanganate, glutaraldehyde, Mexel® 432, and SeaKleen®. For compounds such as chlorine, bromine, chlorine dioxide, and ozone, some training is required. Training and usage information was not available in the reviewed literature for the other biocides.

Generally, personnel safety precautions are required when handling and storing any biocide, although no particular personnel safety concerns were described in the literature for silver ions, Irgarol® 1051, SeaKleen®, or zineb. The biocides with moderate safety concerns (i.e., inhalation or contact risks, but not both) in the literature include copper ions, chlorine dioxide, ozone, Peraclean®, DBPNA, Mexel® 432, PHMB, Grotan®, benzalkonium chloride, potassium permanganate, glutaraldehyde, Dowicil® 75, zinc pyrithione, cationic surfactants (such as $C_{16}$-alkyltrimethylammonium chloride), and TCMTB. Those biocides with significant personnel safety concerns (i.e., any combination of two or more of the following dangers: flammability, inhalation, and contact) include bromine, chlorine, iodine, chloramines, hydrogen peroxide, sodium chlorite, formaldehyde, Sea-Nine®, dichlofluanid, chlorothalonil, ethylene oxide, and phenol.

**Table 4-10. Safety Concerns of Biocides.**

| Biocide | Flammability | Inhalation | Contact | Other |
|---|---|---|---|---|
| **Metal** | | | | |
| Copper Ions | | X | | Poison |
| Silver Ions | | | | None Known |
| **Oxidizing** | | | | |
| ***Halogen containing compounds*** | | | | |
| Bromine | | X | X | Poison |
| Chloramines | | X | X | |
| Chlorine | | X | X | Poison |
| Chlorine Dioxide | | X | | |
| Iodine | | X | X | Strong Oxidizer |
| Sodium Chlorite | | X | X | Strong Oxidizer |
| ***Non-halogen containing compounds*** | | | | |
| Hydrogen Peroxide | | X | X | Strong Oxidizer |
| Ozone | | X | | Strong Oxidizer |
| Potassium Permanganate | | X | | Strong Oxidizer |
| **Non-oxidizing** | | | | |

**Table 4-10. Safety Concerns of Biocides (cont'd).**

| Biocide | Flammability | Inhalation | Contact | Other |
|---|---|---|---|---|
| ***Acids*** | | | | |
| Peraclean® (peracetic acid) | | X | | |
| ***Aldehydes*** | | | | |
| Formaldehyde | X | X | X | |
| Glutaraldehyde | | X | | |
| ***Amines and halogenated amides*** | | | | |
| DBNPA | | | X | Strong Oxidizer |
| Mexel 432 | | X | | |
| ***Heterocyclic ketones*** | | | | |
| Polyhexamethylene Biguanide (PHMB) | | | X | |
| Sea-Nine® (Kathon® 5287) | | X | X | |
| **Others** | | | | |
| Benzalkonium Chloride | | X | | |
| Cationic surfactants (example: $C_{16}$-alkyltrimethylammonium chloride) | | | X | |
| Chlorothalonil | | X | X | |
| Dichlofluanid | | X | X | |
| Dowicil® 75 | | | X | |
| Ethylene Oxide | X | X | X | |
| Grotan® | | | X | |
| Irgarol® 1051 | | | | None Known |
| Phenol | X | X | X | Poison |
| SeaKleen® (Vitamin K) | | | | None Known |
| TCMTB | | | X | |
| Zinc pyrithione | | X | | |
| Zineb (thiocarbamate) | | | | None Known |

### 4.8 Laws and Regulations Governing the Use of Biocides

Biocides that are intended for use inside the ballast tank or on the outside of a vessel's hull (i.e., anti-fouling agents) are nationally and internationally regulated by a number of statutes, conventions, and treaties (Table 4-11). These laws and regulations apply to both the transport and handling of the material as well as their use and discharge into receiving waters. In the United States, pertinent regulations aim to protect the health and safety of handlers as well as the integrity of the receiving ecosystem. Many of the laws reviewed are likely relevant to the use of biocides to treat ballast water because the biocide-treated ballast water will be discharged at the vessel's destination and the biocide or its byproducts (although used to protect the receiving waters) may be considered a pollutant under the these regulations. For example, the United States' Clean Water Act of 1972 makes it unlawful for a pollutant to be discharged from a point

source into navigable waters, unless a valid permit is obtained. Although ballast water (and the organisms contained therein) is not considered a pollutant by the EPA[2], the Clean Water Act may still apply to any biocidal chemical or other substance added to the ballast tank prior to discharge.

A second United States law that may apply to biocides used to treat ballast water is the Marine Protection, Research, and Sanctuaries Act [MPRSA]) of 1972. This act prohibits any person, without a permit, from transporting from inside or outside the U.S. any material for the purpose of dumping (e.g., disposal versus discharge) it into ocean waters. While discharge of ballast water is not generally considered disposal (dumping), the applicability of this statute to biocides and byproducts used in the treatment of ballast water should be clarified.

A third United States law that may apply to the discharge of biocide-treated water is the Endangered Species Act (ESA) of 1973, which prohibits any action that can adversely affect an endangered or threatened species or its habitat. In compliance with the ESA, the U.S. Environmental Protection Agency (EPA) must ensure that use of the pesticides it registers will not harm endangered or threatened species. It is not clear how biocides not defined as pesticides would be regulated under this statute.

U.S. statutes that apply to the handling and use of the biocide itself include the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1947. This act governs the sale, distribution, and use of pesticides through a licensing system. Under FIFRA, all pesticides used in the United States must have an EPA registration, which ensures that pesticides will be properly labeled and will not cause unreasonable harm to the environment. In addition, all users must complete an exam certifying them as applicators of pesticides. It is not clear to what extent biocides are termed or equated to pesticides, thus any biocide that is defined as pesticide probably would be regulated under FIFRA. Application of FIFRA to those biocides that are not defined as pesticides must be evaluated. A U.S. Army Corps of Engineers technical paper (1994) reported that "aquatic biocide use inconsistent with label instructions may result in enforcement action by EPA under FIFRA or by states having pesticide use enforcement primacy under FIFRA." This conclusion is based on the fact that the existing toxicity data for many biocides indicate that use at recommended concentrations will not comply with State water quality standards.

[2] In September 2003, the EPA denied a petition filed by the Pacific Environmental Advocacy Center, a coalition of environmental groups and fishermen, that sought to have the EPA revoke a section of the Clean Water Act. The section in question specifically exempts the following discharges from needing a National Pollutant Discharge Elimination System (NPDES) permit: "any discharge of sewage from vessels, effluent from properly functioning marine engines, laundry, shower, and galley sink wastes, or *any other discharge incidental to the normal operation of a vessel*." The EPA denied the petition, deciding that ballast water will not be considered a pollutant under the Clean Water Act.

**Table 4-11. National and International Regulations, Statutes, Conventions, and Treaties.**

| Regulation/Statute/Convention (Year Enacted) | Country(ies)/ Region(s) | Brief Description |
|---|---|---|
| Clean Water Act (1972) | United States of America | Makes it unlawful to discharge any pollutant from a point source into navigable waters, unless a permit is obtained under CWA provisions |
| Ocean Dumping Act (MPRSA) (1972) | United States of America | Prohibits, without a permit, transporting from the U.S. or from a location outside the U.S. any material for the purpose of dumping it into ocean waters |
| Occupational Safety and Health Act (1970) | United States of America | Requires employers to provide their workers with a place of employment free from recognized hazards to safety and health. |
| Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (1947) | United States of America | Governs the sale, distribution, and use of pesticides generally through a licensing system. |
| Endangered Species Act (ESA) (1973) | United States of America | Prohibits any action that can adversely affect an endangered or threatened species or its habitat. In compliance with ESA, EPA must ensure that use of the pesticides it registers will not harm these species. |
| Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) (1976) | Mediterranean Sea | To prevent, abate, and combat pollution of the Mediterranean Sea area caused by discharges from ships and to ensure the implementation in that area of the rules relating to this type of pollution. |
| Protocol Concerning Mediterranean Specially Protected Areas (1982) | Mediterranean Sea | To take the measures required against the dumping or discharge of wastes and other substances that are likely, directly or indirectly, to impair the integrity of the specially protected area. |
| Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea (1975) | Mediterranean Sea | To take all appropriate measures to prevent and abate pollution of the Mediterranean Sea area caused by dumping from ships and aircraft. |
| Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) (1974) | Baltic area | To abate pollution of the Baltic Sea area caused by discharges through rivers, estuaries, outfalls and pipelines, dumping and normal operations of vessels, as well as through airborne pollutants. |
| Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) (1997) | Northeast Atlantic nations | To prevent and eliminate pollution and protect the maritime area against the adverse effects of human activities so as to safeguard human health and to conserve maritime ecosystems. |
| Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region (1981) | West coastal African nations | To prevent, reduce, combat and control pollution in the Convention area caused by normal or accidental discharges from ships, and to ensure the effective application in the Convention area of the internationally recognized rules and standards relating to the control of this type of pollution. |
| East Asian Seas Action Plan (1981) | East Asian nations | To provide for the protection and sustainable development of the marine environment and the coastal areas for the promotion of the health and well-being of present and future generations. |
| Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (1981) | Caribbean nations | To prevent, reduce, and control the following types of pollution: pollution from ships, pollution caused by dumping, pollution from sea-bed activities, airborne pollution, and pollution from land-based sources and activities. |

## Table 4-11. National and International Regulations, Statutes, Conventions, and Treaties (cont'd).

| Regulation/Statute/Convention (Year Enacted) | Country(ies)/ Region(s) | Brief Description |
|---|---|---|
| Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region (1985) | East coastal African nations | To prevent, reduce and combat pollution of the Convention area caused by discharges from ships and to ensure the effective implementation of the applicable international rules and standards established by, or within the framework of, the competent international organization. |
| Northwest Pacific Action Plan (1994) | Northwestern Pacific nations | To ensure the wise use, development, and management of the coastal and marine environment so as to obtain long-term benefits for humans, while protecting human health, ecological integrity, and the region's sustainability. |
| Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific (1981) | Nations of the western coasts of Central and South America | To prevent and control pollution of the marine environment including, (a) Release of toxic, harmful or noxious substances, especially those which are persistent: (i) From land-based sources; (ii) From or through the atmosphere; and (iii) By dumping; and (b) Pollution from vessels, in particular, measures for preventing intentional discharges |
| Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment (1982) | Nations bordering the Red Sea or the Gulf of Aden | To prevent, abate and combat pollution in the area caused by intentional or accidental discharges from ships and to ensure effective compliance in the area with generally recognized international rules relating to the control of this type of pollution. |
| Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region (1982) | Nations of the South Pacific | To prevent, reduce, and control pollution from any source and to ensure sound environmental management, using the best practicable means and in accordance with capabilities. All appropriate measures shall be taken to prevent, reduce, and control pollution in the Convention Area by dumping. |
| South Asian Seas Action Plan (1995) | South Asian nations | To provide for the protection and sustainable development of the marine environment and the coastal areas for the promotion of the health and well-being of present and future generations. |
| Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution (1976) | Nations surrounding Persian Gulf | To prevent, abate and combat pollution of the marine environment |
| Northeast Pacific Action Plan (2001) | Northeastern Pacific nations | To control, halt, and prevent any further degradation and deterioration of the coastal and marine environment and its resources and to ensure long-term sustainability. |
| Biocidal Products Directive 98/8/EC (Anti-fouling) (1993) | European Union | To harmonize the European market for biocidal products and their active substances and to provide a high level of protection for humans, animals, and the environment. The removal of barriers to trade will not be at the expense of lowering health and environmental protection. |
| IMO Anti-Fouling Systems Convention (2001) | IMO | Prohibits the use of harmful organotins in anti-fouling paints used on ships and will establish a mechanism to prevent the potential future use of other harmful substances in anti-fouling systems |
| Anti-Fouling Legislation | Canada | All anti-foulings applied in Canada require registration with the government. Application of TBT anti-foulings is completely banned from 10/31/02 forward. All registered anti-foulings containing copper must have a release rate of less than 40 µg copper/cm$^2$/day. |
| Anti-Fouling Legislation (Organotin Antifouling Paint Control [33 U.S.C. 2401]) (1988) | United States of America | All anti-foulings applied in the U.S. require registration both federally (EPA) and with each state's Environmental Agency. TBT anti-foulings must not be applied to vessels under 25m in length (aluminum hulls exempted) and must have a TBT release rate of less than 4 ug TBT/cm$^2$ paint/day. |
| Anti-Fouling Legislation | Malta | All anti-foulings applied in Malta require registration. Application of TBT anti-foulings is banned on vessels under 25 meters in length. |

## Table 4-11. National and International Regulations, Statutes, Conventions, and Treaties (cont'd).

| Regulation/Statute/Convention (Year Enacted) | Country(ies)/ Region(s) | Brief Description |
|---|---|---|
| Anti-Fouling Legislation | Sweden | Registrations for TBT anti-foulings have been canceled. Anti-fouling products containing copper banned for use on pleasure craft in the Baltic Sea. Products used on pleasure craft on the West Coast of Sweden is subject to copper leaching rate restrictions. Must show leaching rate < 200 ug copper/$cm^2$ in first 14 days and < 350 ug copper/$cm^2$ in first 30 days after immersion. |
| Anti-Fouling Legislation | United Kingdom | Registrations for TBT anti-foulings have been canceled. Registrations for use of organic biocides Irgarol 1051 and diuron in anti-fouling of pleasure craft have been canceled. |
| Anti-Fouling Legislation | Netherlands | Use of products containing copper are banned for pleasure craft operating in fresh water areas. |
| Anti-Fouling Legislation | Japan | Anti-fouling paints containing biocides applied in Japan do not require registration but must contain biocides approved by Government/Industry committees, e.g., JSA/MITI. Application of TBT anti-foulings in Japan has been totally forbidden since 1992. |
| Anti-Fouling Legislation | Hong Kong | All anti-fouling paints applied in Hong Kong require registration. All TBT products must have a biocide release rate of less than 4ug TBT/$cm^2$/day. |
| Anti-Fouling Legislation | Korea | Use of TBT on small ships is forbidden. Korean government is considering the introduction of a registration scheme for anti-foulings. |
| Anti-Fouling Legislation | Australia | All anti-foulings applied in Australia require registration with NRA (National Registration Authority) under pesticide laws. Registration of TBT anti-foulings forbidden from June 2003 forward. |
| Anti-Fouling Legislation | New Zealand | All anti-foulings applied must be registered. Application of TBT anti-foulings is forbidden. |
| Marketing and Use Directive 76/769/EEC (1976) | European Union | To protect the general public and the environment from certain dangerous substances and preparations and to ensure the proper functioning of the common market by approximating the laws of the Member States relating to the marketing and use of these substances. |
| Council Directive 1967/548/EEC (1967) | European Union | To approximate the national measures on the classification, packaging and labeling of dangerous substances in order to protect public health and the environment and ensure the free movement of such products. |
| Dangerous Preparation Directive 88/379/EEC (1967) | European Union | The DPD's prime aim is to identify and control dangerous finished product formulations. |
| New Substances Directive 92/32/EEC (1981) | European Union | A new substance is one which was first marketed after September 18, 1981. Manufacturers are required to (1) provide information on themselves as manufacturers, and on the identity of the substance they are producing; (2) carry out tests to identify the properties of the substance, as well as gather data on toxicology and ecotoxicology; (3) provide information on the processes used in the production of the new substance, as well as the proposed use(s); (4) propose guidelines for classification and labeling, as well as safety precautions; and (5) draft a risk assessment. |
| Existing Substances Regulation 793/93/EEC (1981) | European Union | An existing substance is defined as one listed in the European Inventory of Existing Commercial Chemical Substances before September 18, 1981. Regulation 793/93/EEC set up a program designed to identify and control the risks posed by EINECS substances of high production volumes. |
| Canada Shipping Act – Part (XV): Pollutant Substances Regulations (CRC, c. 1458) | Canada | Provides for the Governor in Council to make regulations with respect to prohibiting the discharge from ships of pollutants and prescribing substances and classes of substances that are pollutants. Under subsection 656(2) a pollutant can only be discharged from a ship in accordance with a permit. |

### Table 4-11. National and International Regulations, Statutes, Conventions, and Treaties (cont'd).

| Regulation/Statute/Convention (Year Enacted) | Country(ies)/ Region(s) | Brief Description |
|---|---|---|
| Canada Pest Control Products Act | Canada | Regulates products used for the control of pests and the organic functions of plants and animals. Export of pesticide products from Canada and movement of products between provinces is prohibited unless the manufacturing establishment is licensed and complies with prescribed conditions. There is also a general prohibition against manufacture, storage, display, distribution or use of pest control products under unsafe conditions. |
| The Merchant Shipping Regulations (Control of Pollution by Noxious Liquid Substances in Bulk), Schedule I (1987) | Great Britain | Glutaraldehyde is a Class D substance. Discharge into the sea is prohibited and discharge of residual mixtures is subject to restrictions. |

The Occupational Safety and Health Act (OSHA) of 1970, which aims to protect workers from harm when handling potentially dangerous substances, has relevance to the use of biocides for ballast water treatment. According to a list provided with the law's text, the following biocides identified for this investigation are regulated under OSHA: ozone, chlorine dioxide, chlorine, glutaraldehyde, ethylene oxide, formaldehyde, hydrogen peroxide, and phenol.

The international community has adopted a suite of protective treaties designed to prevent marine pollution. Virtually every nation with marine coastline has signed one of fourteen conventions that have been designed to protect coastal and ocean waters in the past few decades. All of these conventions cover very similar issues that would be of concern to a country economically and culturally dependent on its coastal waters. For example, the Nairobi Convention of 1985 (of which the signatories include Somalia, Kenya, Tanzania, Mozambique, South Africa, Comoros, Seychelles, Madagascar, La Réunion, and Mauritius) requires, among other things, that "the Contracting Parties take all appropriate measures to prevent, reduce, and combat pollution of the Convention area caused by discharges from ships and… to ensure the effective implementation of the applicable international rules and standards established by…the competent international organization." Another regional convention is the Paris Convention of 1992, which includes as contracting parties the nations bordering the Northeast Atlantic Ocean. The Paris Convention (OSPAR) aims to "to take all possible steps to prevent and eliminate pollution and the necessary measures to protect the maritime area against the adverse effects of human activities so as to safeguard human health and to conserve maritime ecosystems…". The remaining twelve conventions cover the Mediterranean Sea, the Baltic Sea, West and Central Africa, East Asian seas, the Caribbean nations, the Northwest Pacific, the Northeast Pacific, the Southeast Pacific, the Red Sea and the Gulf of Aden, the South Pacific, South Asian seas, and the Persian Gulf region. All of these conventions have the same goal: to protect the coastal and marine environments from pollution in general and, often, specifically from vessel discharge.

In response to international concern about aquatic nuisance species, the International Maritime Organization (IMO) Assembly adopted the International Convention for the Control and Management of Ships Ballast Water & Sediments in February 2004. The Convention will enter into force one year after it is ratified by 30 states, which represent 35 percent of world merchant shipping tonnage. The parties to the convention will agree to "prevent, minimize and ultimately eliminate the transfer of harmful aquatic organisms and pathogens through the control and management of ships' ballast water and sediments." (GloBallast, 2004). In addition, parties will agree to provide reception facilities at those ports where the cleaning or repair of ballast tanks will occur, promote further research on ballast water management, and ensure that vessels in their port are properly certified and inspected. The convention also includes specific ballast water exchange standards (which mandate that a vessel must exchange at least 95 percent of its ballast tank volume) and performance standards (which instruct the amount of organisms that may be discharged per unit of tank volume).

Many nations have adopted separate legislation designed to cover biocides that are applied to the outside of a vessel's hull. These biocides, often called antifouling agents, help prevent barnacles, algae, and other organisms from growing on the submerged surfaces of a vessel. These regulations recognize that potentially dangerous non-indigenous species can be introduced in

ways other than through the discharge of ballast water. The nations that have enacted laws prohibiting or severely restricting the use of anti-fouling agents include, among others, the United States, Canada, Sweden, the United Kingdom, the Netherlands, Japan, Korea, Australia, and New Zealand. Most of the anti-fouling legislation from these countries specifically target tributyltins (also known as TBTs), slow-degrading, highly toxic compounds that have proven negative impacts on native species and human health. TBTs are often added to hull paint so that vessel owners can acquire some measure of structural protection when repainting their vessel. Most of the aforementioned nations have completely banned any further application of TBTs (any vessel with TBT already applied must be registered) while just a few require that the vessel owner demonstrate a slow leaching rate. Passing these antifouling laws show the true concern most nations have for their marine ecosystems and the health of their human citizens.

## 5.0 Application of Biocides to Ballast Water Treatment

Most of the biocides identified and reviewed in this investigation were developed for drinking water or sewage applications, and not for saltwater applications (see Sections 2 and 4). There are two major questions regarding their efficacy for treating ballast water. The first relates to the effectiveness against the range of organism types found in ballast water. The second is the ability to treat water with high salt or particulate and organic matter content.

Only a few of the biocides identified demonstrated fair to good biocidal activity against a broad spectrum of organisms (Table 4-2). These include chlorine, chlorine dioxide, hydrogen peroxide, glutaraldehyde, Peraclean®, SeaKleen®, phenol, and cationic surfactants (such as $C_{16}$-alkyltrimethylammonium chloride). Therefore, for the purposes of this discussion, all these biocides are designated as Group A biocides and are further evaluated below (Section 5.1).

Several other biocides demonstrated fair to good biocidal activity, but only against a subset of the range of target organisms typical of ballast water. The lack of experimental or other evidence to support the ability of these biocides to kill or inactivate all types of organisms makes it difficult to judge their ability to effectively treat ballast water. It is recommended that additional information be obtained and reviewed before their potential application to ballast water is determined. These biocides include copper, bromine, iodine, sodium chlorite, chloramines, ozone, formaldehyde, Mexel® 432, DBNPA, PHMB, TCMTB, benzalkonium chloride, chlorothalonil, dichlofluanid, Dowicil® 75, ethylene oxide, Grotan®, Irgarol® 1051, zinc pyrithione, triclosan, and zineb. These biocides were retained for further evaluation for potential use in ballast water and are designated as Group B biocides (Section 5.2).

The information reviewed indicated that silver, Sea-Nine®, and potassium permanganate were not effective against viruses and bacteria. Because of these and other limitations, these biocides were not further evaluated in this report. It is recommended that additional information be obtained and reviewed before their potential application to ballast water is determined.

### 5.1 Group A Biocides—Biocides with Fair to Good Efficacy against a Broad Spectrum of Organisms

A closer examination of the Group A biocides with respect to certain evaluation criteria is provided in Table 5-1. All eight biocides in Group A are commercially available and, despite price variability according to supplier and biocide concentration and form, most of these biocides are not considered cost prohibitive.

All but two of these biocides, SeaKleen® and phenol, are used to disinfect water systems so their effectiveness on large volumes of water has been researched. Phenol is an antifouling agent used in paints applied to ship hulls and does not have the research supporting its application to treat large volumes of water, as the other biocides do. However, SeaKleen® and phenol still possess some of the qualities necessary for potential use in ballast water, such as having no toxic byproducts, no recalcitrance in the environment, and being relatively cost effective. As indicated in Table 5-1, none of the biocides in Group A are recalcitrant and, therefore, have relatively short degradation times. Toxic byproducts are not a major concern for glutaraldehyde, SeaKleen®, phenol, and cationic surfactants (such as $C_{16}$-alkyltrimethylammonium chloride).

Under some environmental conditions, chlorine dioxide and hydrogen peroxide can form toxic byproducts. Chlorine can produce trihalomethanes and haloacetic acid as byproducts, both of which are toxic. The efficacy of chlorine dioxide does not vary with pH. However, glutaraldehyde, chlorine, and hydrogen peroxide can all be impacted by pH values. For example, glutaraldehyde becomes more effective as pH values increase. Adsorption to suspended solids and sediments is not a concern for chlorine dioxide, glutaraldehyde, SeaKleen®, and cationic surfactants (such as $C_{16}$-alkyltrimethylammonium chloride). Neither regulatory nor significant safety concerns were identified for glutaraldehyde or SeaKleen®. Based on the literature and vendor information, shipboard application is not considered difficult for glutaraldehyde, Peraclean®, or SeaKleen®. Finally, the costs of maintenance, installation, and operation of the respective technologies are considered relatively low for Peraclean® or SeaKleen®. The other biocides in Table 5-1 have relatively moderate costs (i.e., not prohibitive) associated with them, except for chlorine dioxide. Based on this evaluation, chlorine dioxide, glutaraldehyde, SeaKleen®, and cationic surfactants (such as $C_{16}$-alkyltrimethylammonium chloride) are identified as the leading potential agents for ballast water treatment in both marine and freshwater environments.

### 5.2 Group B Biocides—Biocides with Fair to Good Efficacy against a Narrow Spectrum of Organisms

Group B biocides show potential for treating ballast water, however, additional information is required to fully determine their applicability. These biocides include copper, bromine, iodine, sodium chlorite, chloramines, ozone, formaldehyde, ethylene oxide, and Dowacil® 75. It is recommended (see Section 6) that additional information be reviewed for these biocides to determine their potential for ballast water treatment.

## Table 5-1. Evaluation of Group A and Group B Biocides.

| Biocide | Effective against Broad Range of Organisms?* | pH Inhibition | Adsorp-tion | Toxic byproducts | Recalci-trance | Shipboard Application Difficult | Cost Prohibitive | Safety Concerns | Regulatory Concerns |
|---|---|---|---|---|---|---|---|---|---|
| **Group A Biocides** | | | | | | | | | |
| Chlorine | Yes | Yes | Yes | Yes | Some | Yes | Somewhat | Yes | Yes |
| Chlorine dioxide | Yes | No | No | Yes† | Some | Somewhat | Yes | Yes | Some |
| Hydrogen peroxide | Yes | Yes | Un-known | Yes† | No | Somewhat | Somewhat | Yes | Some |
| Glutaraldehyde | Yes | Yes | No | No | No | No | Somewhat | No | No |
| Peraclean® | Yes | Unknown | Yes | Unknown | Unknown | No | No | Yes | Some |
| Cationic surfactants | Yes | Unknown | No | Unknown | Some | Unknown | Somewhat | Yes | Some |
| SeaKleen® | Yes | Unknown | No | No | No | No | No | No | No |
| Phenol | Yes | Unknown | Yes | No | No | Somewhat | Somewhat | Yes | Yes |
| **Group B Biocides** | | | | | | | | | |
| Copper | Yes | Some | Yes | No | Some | Somewhat | No | Yes | Yes |
| Bromine | No | Yes | Yes | Yes | Unknown | Yes | No | Yes | No |
| Iodine | No | Unknown | Un-known | Yes | Unknown | Somewhat | Somewhat | Yes | No |
| Sodium chlorite | No | Unknown | Un-known | Yes | Some | Somewhat | No | Yes | Yes |
| Chloramines | No | No | Some | Yes | Some | Somewhat | No | Yes | Unknown |
| Ozone | No | No | Yes | Yes† | No | Yes | Yes | Yes | Yes |
| Formaldehyde | No | Some | Un-known | No | No | Somewhat | Somewhat | Yes | Yes |
| Ethylene oxide | No | No | No | Yes† | No | Yes | Unknown | Yes | Yes |
| Dowicil® 75 | No | No | Yes | Yes | No | Unknown | Unknown | Yes | Some |

* If the biocide was found to be effective against six or more of the nine target organisms, a "yes" was entered. If it was effective against fewer than six, a "no" was entered.

† Toxic byproducts may form depending on existing environmental conditions

A comparison of the nine biocides in Group B with respect to the evaluation criteria is provided in Table 5-1. Based on the data obtained and evaluated for these nine biocides, recalcitrance is an issue for copper, sodium chlorite, and chloramines. Formation of toxic byproducts can be an issue for bromine, iodine, sodium chlorite, chloramines, and Dowicil® 75. Adsorption to suspended solids or sediment is expected to occur for copper, bromine, chloramines, ozone, and Dowicil® 75. Some level of safety is expected to be a concern for all Group B biocides, while regulatory concerns exist for copper, sodium chlorite, ozone, formaldehyde, ethylene oxide, and Dowicil® 75. For example, the maintenance and power requirements of ozone generation equipment along with the corrosive character of ozone make shipboard application more difficult and questions arise on the suitability of ozone as a stand-alone biocide. Based on the information reviewed, the biocides in Group B do not appear to be strong candidates for the treatment of ballast water at this time.

## 6.0 Summary and Recommendations

The literature search conducted to obtain available information on various aspects of biocides with the potential for treating ballast water, including their biological treatment efficacy, environmental acceptability, shipboard practicality, and associated costs, identified 32 candidate biocides. The list included biocides that are commonly used in marine antifouling paints or are being evaluated for use as alternative antifouling agents. The information gathered from the literature search was reviewed and organized into a searchable relational database with the ability to generate one fact sheet for each biocide, summarizing the information gathered on the evaluation criteria. Information regarding international conventions and United States laws and regulations for the use of biocides indicate that registration requirements of biocides are uncertain and need clarification.

An assessment of the biocides against a set of evaluation criteria allowed a qualitative comparison of the identified biocides according to their potential usefulness for ballast water treatment. Based on the results of the comparison, biocides were either identified as potential candidates for application in ballast water and evaluated more closely, identified as chemicals requiring additional information for further evaluation, or identified as unlikely candidates for ballast water treatment.

The qualitative evaluation and comparison found the following biocides have potential for use in ballast water treatment in both marine and freshwater environments: chlorine dioxide, glutaraldehyde, SeaKleen®, and cationic surfactants (such as $C_{16}$-alkyltrimethylammonium chloride).

The qualitative evaluation and comparison also concluded the following:

- Copper, bromine, iodine, sodium chlorite, chloramines, ozone, formaldehyde, ethylene oxide, and Dowicil® 75 were determined to be poor potential biocides for ballast water;
- Mexel® 432, Dibromonitrilopropionamide (DBNPA), Polyhexamethylene biguanide (PHMB), 2-thiocyanomethylthio benzothiazole (TCMTB), benzalkonium chloride, chlorine, chlorothalonil, dichlofluanid, Grotan®, hydrogen peroxide, Peraclean®, zinc pyrithione, Irgarol® 1051, phenol, triclosan, and zineb were identified as biocides with demonstrated efficacy against some of the target organisms, but recommending these

biocides for ballast water treatment requires information regarding other evaluation criteria.

Although treatment of ballast water with biocides is an attractive option primarily because of the potential to eradicate a range of organisms and the potential ease of incorporation into both existing and future vessel designs, a number of questions regarding their use in ballast water remain unanswered. For example, factors such as the degradation rate of a particular biocide and the potential release of undesirable byproducts into the receiving waters must be known. In addition, many properties of seawater raise questions on whether biocides can be applied safely to the marine environment. Although biocides have been used extensively in certain industries for disinfection, the ballast tank and shipboard environments are different and distinct from these applications and may not be compatible with certain biocides. Thus, the overall effectiveness of many of the 32 identified biocides in treating ballast water is uncertain.

While the evaluation of biocides shows several that have potential application for ballast water treatment, much of the information obtained from the literature search was not specifically the result of scientific research targeted for ballast water treatment. Thus, the use of such information to determine ballast water applicability must be used cautiously. To address these information shortcomings, the following recommendations are made to support future decisions on the applicability of biocide use in ballast water:

- Continue research using environmentally friendly chemicals as biocides in the marine environment (similar to glutaraldehyde study by Lubomudrov *et al.,* 1997).
- Conduct laboratory bench-scale study aimed at the effects of marine environmental conditions, efficacy, and fate of potential biocides.
- Encourage pilot-scale design studies of ballast water biocidal treatment processes.

## 7.0 References

Association Internationale de la Savonnerie (AISE). 1997. Benefits and Safety Aspects of Hypochlorite – Briefing Document. Association Internationale de la Savonnerie, de la Détergence et des Produits d'Entretien. Brussels, Belgium.

Arends, E., Gollasch, S., Grashof, M.G.J., Hulsbeek, J.J.W., Ietswaart, T., and R.M. de Vogel. 2001. Standards for Ballast Water Treatment. Ministry of Transport and Public Works, North Sea Directorate. The Hague.

Bender, M. E., Roberts, M. H., Diaz, R., and R.J. Huggett. 1977. Effects of residual chlorine on estuarine organisms. Pollution Engineering and Technology, 5 (Biofouling Control Proced.: Technol. Ecol. Eff.): 101-108.

Bhaskar, R., and J. Pederson. 2003. Exotic Species: an ecological roulette with nature. http://massbay.mit.edu/resources/pdf/factsheet.pdf.

Bitton, G. 1999. Wastewater Microbiology. 2nd ed. Wiley-Liss, Inc., NY.

Block, S.S. 1991. Disinfection, Sterilization, and Preservation. S.S. Block (Ed.) Lea & Febiger, Philadelphia, PA.

Capuzzo, J.M., Goldman, J.C., Davidson, J.A., and S.A. Lawrence. 1977. Chlorinated cooling waters in the marine environment: development of effluent guidelines. Marine Pollution Bulletin 8(7):161-163.

Capuzzo, J.M., Lawrence, S.A., and J.A. Davidson. 1976. Combined toxicity of free chlorine, chloramine and temperature to stage I larvae of the American lobster *Homarus americanus*. Water Research 10(12):1093-1099.

Carlton, J.T., Reid, D.M., van Leeuwen, H. 1995. Shipping Study: The Role of Shipping in the Introduction of Non- indigenous Aquatic Organisms to the Coastal Waters of the United States (Other than the Great Lakes) and an Analysis of Control Options. A Report of the United States Fish and Wildlife Service, Washington D.C., and the National Sea Grant College Program Connecticut Sea Grant.

Chattopadhyay, D., Chattopadhyay, S., Lyon, W.G., and Wilson, J.T. 2002. Effect of Surfactants on the Survival and Sorption of Viruses. Environmental Science & Technology. 36(19): 4017-4024.

Cooper, W.J., G.M. Dethloff, R.W. Gensemer, M.L. House, R.A. Mueller, G.M. Ruiz, W. A. Stubblefield, J.R. Cordell, P.A. Dinnel, R.P. Herwig, J.A. Kopp, J.C. Perrins, G.M. Sonnevil, E. VanderWende. 2002. Full-Scale Ozone Ballast Water Treatment for removal of Marine Invasive Species. Arlington, VA: Nutech Publication. 156 pp.

Department of Transportation (DOT). 2002. Hazardous Substances Table. 49 CFR 172.101. www.myregs.com/dotrspa.

European Parliament and Council. 1998. Directive 98/08/EC of the European Parliament and of the Council of 16 February 1998 concerning the placing of biocidal products on the market. OJ 99/L123/01.

GloBallast. 2004. Ballast Water Convention Adopted. http://globallast.imo.org.

Glosten-Herbert-Hyde Marine. 2002. Full-Scale Design Studies of Ballast Water Treatment Systems. Northeast Midwest Institute, Washington, D.C.

Greenman, D., Mullen, K., and S. Parmar. 1997. Ballast Water Treatment Systems: A Feasibility Study, United States Coast Guard Office of Response, Worcester Polytechnic Institute.

Grigorovich, I.A. and H.J. MacIsaac. 1999. First record of *Corophium mucronatum Sars* (Crustacea: Amphipoda) in the Great Lakes. Journal of Great Lakes Research 25: 401-405.

Grothe, D.R. and J.W. Eaton. 1975. Chlorine-induced mortality in fish. Transactions of the American Fisheries Society 104(4):800-802.

Haas, C.N. and J.P. Gould. 1980. Disinfection. Journal of the Water Pollution Control Federation 52(6):1224-1232.

IMO. 2004. International Convention for the Control and Management of Ships Ballast Water & Sediments. London. Friday 13. http://globallast.imo.org/.

Kim, B. R., Anderson, J. E., Mueller, S. A., Gaines, W. A., and A. M. Kendall. 2002. Literature review – efficacy of various disinfectants against Legionella in water systems, Water Research, 36(18): 4433-4444.

Laughton, R., T. Moran, and G. Brown. 1992. A Review and Evaluation of Ballast Water Management and Treatment Options to Reduce the Potential for the introduction of Non-native Species to the Great Lakes. http://www.pollutech.com.

Lubomudrov, L., Moll, R., and M. Parsons. 1997. An Evaluation of the Feasibility and Efficacy of Biocide Application in Controlling the Release of Nonindigenous Aquatic Species from Ballast Water. Final Report. Report to the Michigan Department of Environmental Quality, Office of the Great Lakes. MI.

Montani, S., Meksumpun, S., and K. Ichimi. 1995. Chemical and Physical Treatments for Disinfection of Phytoflagellate Cysts. Journal of Marine Biotechnology 2:179-181.

National Research Council (NRC). 1996. Stemming the Tide: Controlling the Introduction of Non-indigenous Species by Ships' Ballast Water. Washington, DC, National Academy Press.
NRC, see National Research Council.

National Water Quality Management Strategy. 2000. An Introduction to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Oemcke, Darrin. 1999. The Treatment of Ships' Ballast Water. EcoPorts Monograph Series No. 18. Ports Corporation of Queensland.

Raytec Corporation. 2004. dm$ClO_2$ Overview: Chlorine Dioxide. http://www.raytecgroup.com/s/dmClo2Overview.asp.

Rigby, G. and A. Taylor. 2001. Ballast Water Treatment to Minimize the Risks of Introducing Non-indigenous Marine Organisms into Australian Ports. Discussion paper prepared for the Department of Agriculture Fisheries and Forestry Australia as part of the Research Advisory Group Ballast Water Research Program. Ballast Water Report Series No. 13.

Simpson, GD, R.F. Miller, G.D. Laxton, and W.R. Clements. 1993. A Focus on Chlorine Dioxide: The "Ideal" Biocide. Unichem International Inc. Paper No. 472, The NACE Annual Conference and Corrosion Show.

Straub, T.M., Gerba, C.P., Zhou, X., Price, R., and M.T. Yahya. 1995. Synergistic Inactivation of Escherichia coli and MS-2 Coliphage by Chloramine and Cupric Chloride. Water Research 29(3):811-818.

Trofe, T.W., Inman, G.W., Jr., Johnson, J.D. 1980. Kinetics of monochloramine decomposition in the presence of bromide. Environmental Science and Technology 14(5): 544-9.

U.S. Army Corps of Engineers, Waterways Experiment Station. 1994. A Summary of Federal Regulations Related to Use of FIFRA-Registered Biocides and Region 5, U.S. EPA, Use of These Biocides for Zebra Mussel Control. Tech Note. ZMR-1-15. Vicksburg, MS. 3 pp.

U.S. Coast Guard (USCG). 2001. Report to Congress on the Voluntary National Guidelines for Ballast Water Management. U.S. Coast Guard. November 2001. Washington, D.C.

U.S. Coast Guard (USCG). 2003. Programmatic Environmental Assessment for Mandatory Ballast Water Management Program in U.S. Waters. U.S. EPA. 1999. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.

U.S. EPA. 1999. Alternative Disinfectants and Oxidants Guidance Manual. EPA/815-R-99-014.

U.S. EPA. 2001. Aquatic Nuisance Species in Ballast Water Discharges: Issues and Options. Washington, DC. www.epa.gov/owow/invasive_species/ ballast_report/ballast_report.pdf.

Wan, M. T., Van Aggelen, G., Cheng, W., and R.G. Watts. 2000. Acute toxicity of chlorine-produced oxidants (CPO) to the marine invertebrates *Amphiporeia virginiana* and *Eohaustorius washingtonianus*. Can. Bulletin of Environmental Contamination and Toxicology 64(2): 205-212.

Wickramanayake, G. B. 1990. Decontamination Technologies for Release from Bioprocessing Facilities. Part II. Decontamination of Waste Water. CRC Critical Reviews in Environmental Control, 19(5):361-446.

# Appendix A
# Biocide Relational Database

A Microsoft® Access relational database was developed to capture biocide data from multiple literature and biocide vendor interview sources. All of the biocides that were evaluated for this report are included in this database, along with a few others that were not evaluated by the study due to regulatory constraints for application in marine waters. Tables were created to hold information related to the biocides' physiochemical properties, treatment efficacy against target organisms, environmental acceptability, shipboard use, and other vendor information. Laws and regulations that influence the biocides' use and the sources of information are also captured in tables. The entity relationship diagram (ERD) for the biocide database is shown in Figure A-1. It depicts the database tables, columns in each of the tables, primary keys, and the table relationships.

The database also contains forms, queries, and reports that allow for loading, editing, reviewing, and generating standard reports. Upon opening the biocide database, a form opens that requests the selection of a biocide from a pull-down menu to create that biocide's fact sheet. The selected biocide links related data from various tables, generates, and compiles the results of different sub reports into a single biocide fact sheet report. CAS numbers and chemical structure are presented for those biocides for which this information was available. The biocide fact sheets included in Appendix B were created by selecting the respective biocide name to generate the report. Each fact sheet was created as an Adobe Acrobat file for inclusion in this report.

**Table A-1. Key Biocide Database Objects.**

| Object Type | Object Name | Object Description |
|---|---|---|
| Tables | Biocide | Biocide naming convention and description |
| | Biocide_Reg | Biocides impacted by various regulations specific to area |
| | Chosen_Biocide | Selection table to create fact sheet |
| | Citations | Data collected during literature search and vendor contact related to a biocide |
| | Manufacturers | Original tracking of vendor contact information; translated into citations table |
| | Regulations | Description of regulations |
| | Toxicity | Target organism and treatment data related to a citation |
| | Vendor Contacts | Contact information |
| Forms | Biocide | Allows editing and data loading of general biocide data |
| | Biocide_Reg | Allows entry of additional biocides affected by legislation |
| | Citations | Main form to enter citation and biocide information from that source |
| | Regulations | Entry of regulations and areas impacted |
| | Select Biocide to Create Fact Sheet | Look up available biocides from pull-down menu to select which fact sheet to generate |
| | Toxicity | Subform embedded in Citations Form; allows multiple target organisms and treatment doses for a single citation |
| | Vendor Contacts | Allows entry and editing of vendor contacts |
| Reports | Biocide Fact Sheet | Generates the formatted fact sheet for the selected biocide |
| | Biocides ERD | Entity Relationship Diagram for the database |
| | various subreports | Portions of the fact sheet |

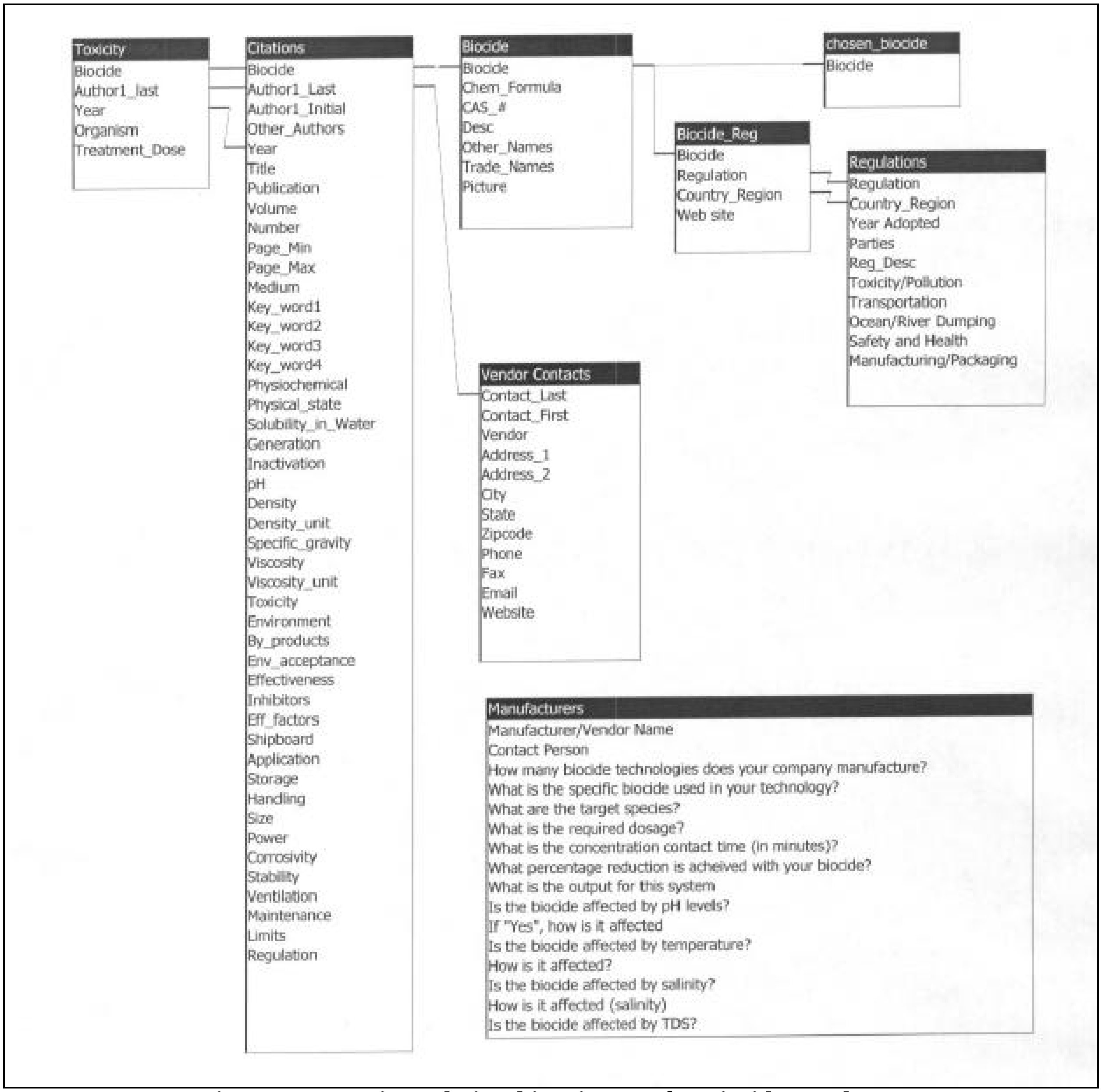
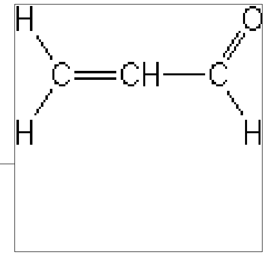



**Figure A-1. Entity Relationship Diagram for Biocide Database.**

# Acrolein

$C_3H_4O$ **CAS_#** 107-02-8



Clear or yellow liquid.

**Other Names** 2-Propen-1-one; 2-propenal; acquinite; Acraldehyde; Acrolein; Acrolein ; acrylaldehyde; Acrylic aldehyde; Allyl aldehyde; aqualine; biocide; crolean; ethylene aldehyde; magnacide; magnacide h; Magnacide H and B; prop-2-en-1-al; prop-2-enal; propenal; Propenaldehyde; propylene aldehyde; slimicide; trans-acrolein;

**Trade_Names**

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Solubility in water | In water, 208 g/kg @ 20 deg C and In water, 2.12X10+5 mg/l @ 25 deg C | Hazardous Substances Data Bank 2004 |
| Stability | very dependent on pH | Hazardous Substances Data Bank 2004 |
| Inactivation | cytotoxic agent | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| amphibians | LC50: very highly toxic | PAN 2004 |
| aquatic plants | EC50 : injury, mortality, population | PAN 2004 |
| bacteria, algae, crustacea, and fish | Acute EC50 and LC50 values between 0.02 and 2.5 mg/liter, bacteria being the most sensitive species; Inhibition of cell multiplication starts at 0.44 mg/l in protozoa (Uronema parduczi Chatton-Lwoff); At 0.21 mg/l in bacteria (Pseudomonas putida); And at 0.04 mg/l in algae (Microcystis aeruginosa). The lowest observed avoidance concn in insects was above 0.1 mg/l for mayfly nymphs (Ephemerella walkeri); 0.1 mg/l for rainbow trout (Salmo gairdneri). The incipient Median Threshold Limit (TLm) for fathead minnow was 84 ug/l in a flow through bioassay; Inhibition of cell multiplication starts at ... 0.04 mg/l in algae (Microcystis aeruginosa). | Hazardous Substances Data Bank 2004 |
| crustaceans | LC50: moderately toxic | PAN 2004 |
| Daphnia magna | LC50 0.23 mg/l/24 hr; 0.083 mg/l/48 hr; No discernible effect conc= 0.034 mg/l. /Conditions of bioassay not specified | Hazardous Substances Data Bank 2004 |
| fish | LC50: highly toxic | PAN 2004 |
| fish | LD50 Carassius auratus (goldfish) <0.08 mg/l/24 hr; LC50 Lepomis macrochirus (bluegill sunfish) 79 ug/l/24 hr /Conditions of bioassay not specified; | Hazardous Substances Data Bank 2004 |
| molluscs | LC50: highly toxic | PAN 2004 |
| phytoplankton | EC50: injury, physiology, population | PAN 2004 |
| Pimephales promelas (fathead minnow) | LC50 14.0 ug/1/96 hr (confidence limit not reliable), flow-through bioassay with measured concentrations, 17.4 deg C, dissolved oxygen 9.3 mg/l, hardness 45.2 mg/l calcium carbonate, alkalinity 42.9 mg/l calcium carbonate, and pH 7.4 | Hazardous Substances Data Bank 2004 |
| zooplankton | LC50: highly toxic | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | n natural unsterilized water was 29 hours compared with 43 hours in sterilized (thymol-treated) water. Half-life in water at pH 5, 150 hr; at pH 7, 120-180 hr; at pH 9, 5 to 40 hr.: not expected to adsorb to suspended solids and sediment based upon the estimated Koc of 3 | Hazardous Substances Data Bank 2004 |
| By Products | Hydrolysis is not expected to occur due to the lack of hydrolyzable functional groups; however primary loss process appears to be an initial hydration (and possibly some biotransformation) to beta-hydroxypropionaldehyde, which is then further biotransformed | Hazardous Substances Data Bank 2004 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | Material must be stowed "on deck only" on a cargo vessel and on a passenger vesel carrying a number of passengers limited to not more than the larger of 25 passengers or one passenger per each 3 m of overal vessel length, but the material is prohibited on passenger vessels in which the limiting number of passengers is exceeded. The material must also be stored away from living quarters. | DOT 2002 |
| Storage | Separate from oxidizing materials, peroxides, acids, and alkalies. Store in a cool, dry, well-ventilated location, protected from sunlight. Outside or detached storage is preferred. Inside storage should be in a standard flammable liquids storage warehouse, room, or cabinet. Do not store uninhibited acrolein | Hazardous Substances Data Bank 2004 |
| Handling | Packing Group I: great degree of danger presented | DOT 2002 |
| Handling | Toxic; may be fatal if inhaled, ingested or absorbed through skin. Inhalation or contact with some of these materials will irritate or burn skin and eyes | Hazardous Substances Data Bank 2004 |

| | | |
|---|---|---|
| Ventilation | Poison and flammable liquid: "on deck only" storage. | DOT 2002 |

### Laws and Regulations

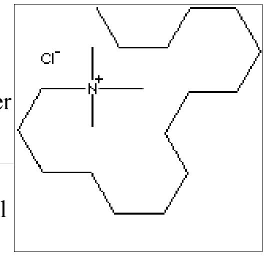
| Country_Region | Regulation | Web site |
|---|---|---|
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |

### Citations

| | | |
|---|---|---|
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| Hazardous Substances Data Bank, , . 2004. | Acrolein | National Library of Medicine Toxnet System : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |

# Alkyltrimethylammonium Chloride (ATMAC)

$CH_3(CH_2)_{15}N(Cl)(CH_3)_3$ **CAS_#** 112-02-7




C16 Alkyltrimethylammonium Chloride; cationic surfactant; quaternary ammonium compound; crystalline white powder or clear liquid used as microbiocide and frequently in hair conditioners and fabric softeners

**Other Names** 1-Hexadecanaminium; Cetyltrimethylammonium chloride; Cetyltrimethylammonium Chloride; 1-Hexadecanaminium, N,N,N-trimethyl-, chloride; Hexadecanaminium, N,N,N-trimethyl-, chloride; Cetyl Trimethyl Ammonium Chloride; Cetrimonium Chloride; Palmityltrimethylammonium chloride; Trimethylhexadecylammonium chloride

**Trade_Names** Adogen 444; Aliquat 6; Arquad 16/28; Arquad 16-29; Arquad 16-50; Barquat CT 29; Cation PB 40; Dehyquart A; Dodigen 1383; Genamin CTAC; Hansaquat 116; HTAC; Intexan CTC 29; Intexsan CTC 29; Intexsan CTC 50; Morpan CHA; NISSAN Cation PB 40; Surfroyal CTAC; Swanol CA 2350; Variquat E 228

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | colorless crystal (alkyltrimethylammonium chloride) | Hazardous Substances Data Bank 2004 |
| pH | 6-9 | Hansa Chemie AG 2002 |
| Density | 1.07 at 20 deg C (alkyltrimethylammonium chloride) | Hazardous Substances Data Bank 2004 |
| Specific gravity | 0.971 | Hansa Chemie AG 2002 |
| Viscosity | 9 mPa*s | Hansa Chemie AG 2002 |
| Solubility in water | very soluble in water; log Kow is -2.17 (alkyltrmethylammoniumm chloride) | Hazardous Substances Data Bank 2004 |
| Stability | avoid excessive heat | Hansa Chemie AG 2002 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| Chlorella pyrenidosa | 96-hour EC50 = 0.22-0.26 mg/L -- 95% confidence | Environmental and Health Assessment 2001 |
| Crustacean Gammarus sp. | 48-hour EC50 = 0.08-0.14 mg/L -- 95% confidence | Environmental and Health Assessment 2001 |
| Dunaliella sp. | 24-hour EC50 = 0.33-0.45 mg/L -- 95% confidence | Environmental and Health Assessment 2001 |
| Fish | 96-hour LC50 = 1-10 mg/L | Hansa Chemie AG 2002 |
| Flatworm Dugesia sp. | 48-hour EC50 = 0.58-0.80 mg/L -- 95% confidence | Environmental and Health Assessment 2001 |
| Oligochaete Dero sp. | 48-hour EC50 = 0.13-0.36 mg/L -- 95% confidence | Environmental and Health Assessment 2001 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | if released to water, trimethylbenzylammonium chloride is expected to adsorb to suspended solids and sediments in water | Hazardous Substances Data Bank 2004 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | cool, dry and well ventilated area | Hansa Chemie AG 2002 |
| Handling | liquid irritating to skin and eyes; goggles or faceshield and rubber gloves required | Hazardous Substances Data Bank 2004 |
| Ventilation | vapor irritating to eyes, nose, and throat; harmful if inhaled; vapor may explode if ignited | Hazardous Substances Data Bank 2004 |

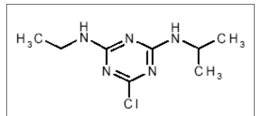
## Laws and Regulations

## Citations

| | | |
|---|---|---|
| Environmental and Health Assessment, , . 2001. | Environmental and Health Assessment of Substances in Household Detergents and Cosmetic Detergent Products | http://www.mst.dk/udgiv/publications/ : - |
| Hansa Chemie AG, , . 2002. | EC Safety Data Sheet | http://www.hansagroup.de/products/pdf/safetysheet/EN-2063.pdf : - |
| Hazardous Substances Data Bank, , . 2004. | TRIMETHYLHEXADECYLAMMONIUM CHLORIDE | National Library of Medicine Toxnet System : - |

# Atrazine

$C_8H_{14}ClN_5$ **CAS_#** 1912-24-9



Selective triazine herbicide. White crystalline solid.

**Other Names** 1,3,5-Triazine-2,4-diamine; 6-chloro-N-ethyl-N'-(1-methylethyl)-; 1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine; 2-chloro-4-ethylamine-6-isopropylamino-S-triazine

**Trade_Names** Argezin, Atazinax, Atranex, Atrataf, Cyazine, Fenamin, Fenatrol, Candex, Weedex, Weedex A, Zeazine; Aatrex, Aktikon, Alazine, Atred, Atratol, Azinotox, Crisazina, Farmco Atrazine, G-30027, Gesaprim, Giffex 4L, Malermais, Primatol, Simazat, and Zeapos

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Solubility in water | 33 mg/L in water at 22 deg C; | Hazardous Substances Data Bank 2004 |
| Stability | rate of hydrolysis increases in either acidic or basic waters; resistant to hydrolysis at neutral pH. | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| amphibians | slightly toxic | PAN 2004 |
| annelida | slightly toxic | PAN 2004 |
| aquatic plants | highly toxic | PAN 2004 |
| crustaceans | slightly toxic | PAN 2004 |
| fish | slightly toxic | PAN 2004 |
| molluscs | slightly toxic | PAN 2004 |
| phytoplankton | highly toxic | PAN 2004 |
| zooplankton | slightly toxic | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | halflife in anaerobic wetland was 224 days; at 25 deg C and pH of 4 half life was 244 days, but with 2% humic acid added the half life decreased to 1.73 days. In Great Lakes water, half lives ranged from 340 to 7,900 hours.; may adsorb to suspended solids and sediments; Koc ranges from 54 - 1164. | Hazardous Substances Data Bank 2004 |
| By Products | hydroxyatrazine under anaerobic conditions with no carbon present | Hazardous Substances Data Bank 2004 |
| Inhibitors | adsorption to suspended solids | Hazardous Substances Data Bank 2004 |
| Effectiveness Factor | rate of hydrolysis increases with humic materials | Hazardous Substances Data Bank 2004 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | shelf life of 3 years in unopened container. Slight sensitivity to light. Keep away from sources of heat, flame, spark. | Hazardous Substances Data Bank 2004 |
| Handling | effects from exposure to substance may include skin irritation, shortness of breath. Rubber gloves and clothing made of cotton recommended. Highly flammable; easily ignited by flame, sparks, heat | Hazardous Substances Data Bank 2004 |

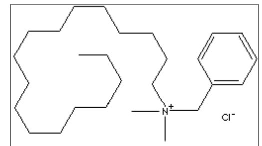
## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |

## Citations


| | | |
|---|---|---|
| Hazardous Substances Data Bank, , . 2004. | Atrazine | National Library of Medicine Toxnet System : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org / : - |

# Benzalkonium Chloride




$C_6H_5CH_2N(CH_3)_2RCl$ **CAS_#** 8001-54-5

white or light yellow/grey solid, or colorless aqueous solution used as a fungicide

**Other Names** alkyl benzyl dimethylammonium chloride; alkyl dimethyl benzylammonium chloride; alkyldimethyl(phenylmethyl) quaternary ammonium chlorides; quaternary ammonium compounds; BTC

**Trade_Names** Ammonyx; Arquad B 100; Barquat MB-50; Barquat MB-80; Bayclean; Benirol; Bionol; BTC 824; Bradophen; Catamin AB; Catamine AB; Cequartyl; Dimanin A; Disinall; Drapolene; Drapolex; Enuclene; Germicin; Germitol; Gesminol; Osvan; Paralkan; Parasterol; Reomergal CB; Rodalon; Zephiral; Zephiran; Zephiran Chloride

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| pH | aqueous solution is slightly alkaline | Hazardous Substances Data Bank 2004 |
| Specific gravity | 0.988 | Hazardous Substances Data Bank 2004 |
| Solubility in water | very soluble | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| Carp | at oxygen saturation and 500 mg/L Damanin A, survival time was 15 minutes | Hazardous Substances Data Bank 2004 |
| Guppy | at oxygen saturation and 500 mg/L Damanin A, survival time was 19 minutes | Hazardous Substances Data Bank 2004 |
| Zebrafish | at oxygen saturation and 500 mg/L Damanin A, survival time was 14 minutes | Hazardous Substances Data Bank 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| By Products | when heated to decomposition release very toxic fumes (hydrogen chloride and nitrogen oxides) | Hazardous Substances Data Bank 2004 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | hygroscopic | Hazardous Substances Data Bank 2004 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| | East Asian Seas Action Plan | |
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and | |

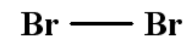
| | | |
|---|---|---|
| | Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean Region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations


| | | |
|---|---|---|
| Beveridge, CM, Parr, A. C. S., Smith, M. J., Kerr, A., Cowling, M. J., and T. Hodgkiess. 1998. | The effect of benzalkonium chloride concentration on nine species of marine diatom | Environmental Pollution 103: 31-36 |
| Hazardous Substances Data Bank, , . 2004. | Benzalkonium Chloride | National Library of Medicine Toxnet System : - |

# Bromine

$Br_2$ **CAS_#** 7726-95-6



Inorganic microbiocide. Available as a heavy, mobile, reddish-brown liquid.

**Other Names** Bromine; bromine gas

**Trade_Names**

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| pH | 6.5 -- 8.5 | Lechter 2003 |
| Inactivation | Bromine causes chemical action and cell/protein disruption | Lechter 2003 |
| Inactivation | Production of halogens and injection of ionized air | Stewart 2003 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| fish | EC50: behavior, mortality | PAN 2004 |
| fish | LC50: highly toxic | PAN 2004 |
| molluscs | EC50: mortality | PAN 2004 |
| Waterborne microorganisms | Brominated resins: most waterborne microorganisms susceptible to doses up to 2 mg/L as Br2; | Lechter 2003 |
| zooplankton | EC50: intoxication, mortality | PAN 2004 |
| zooplankton | LC50: moderately toxic | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | Bromine at certain concentrations is toxic to certain fresh water and marine species. Acceptable levels for specific applications are not known. | Lechter 2003 |
| Byproducts | Bromine: depending on the type of TTHM formation potential and pH, some brominated organics may form; reduced form of free bromine--bromide ion, Br- | Lechter 2003 |
| Byproducts | Low levels of bromoform, but still below drinking water standards | Stewart 2003 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | Keep as cool as reasonably possible; stow clear of living quarters, separated from flammable solids, oxidizers, and radioactive materials. | DOT 2002 |
| Handling | Packing Group I: great degree of danger presented | DOT 2002 |
| Corrosivity | Corrosive Hazard Class of material | DOT 2002 |
| Corrosivity | Bromine is naturally very corrosive but when it is diluted with this system (between 0.2 and 2 ppm), there is no risk of corrosivity. | Lechter 2003 |
| Corrosivity | None | Stewart 2003 |
| Power Requirements | Needs research | Lechter 2003 |
| Power Requirements | < 1,500 KW | Stewart 2003 |
| Ventilation | Corrosive and poison. | DOT 2002 |
| Maintenance | Bromine cartridges need to be periodically changed. | Lechter 2003 |
| Maintenance | Regular visual inspections and reading the maintenance log. Annual change out of Ionz cells and chlorine generators. | Stewart 2003 |

## Laws and Regulations

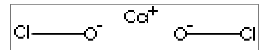
| Country_Region | Regulation | Web site |
|---|---|---|
| | East Asian Seas Action Plan | |
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Canada | Canada Shipping Act - Part (XV): Pollutant Substances Regulations (CRC, c. 1458) | http://www.tc.gc.ca/acts-regulations/GENERAL/C/csa/regulations/050/csa052/csa52.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |

| | | |
|---|---|---|
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean Region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

**Citations**


| | | |
|---|---|---|
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| Lechter, J, . 2003. | Telephone conversation with Jerry Letcher, Sales Manager | Pentair Water Treatment/Plymouth Products : - |
| Oemcke, D, . 1999. | The Treatment of Ships' Ballast Water | EcoPorts Monograph Series 18: - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Stewart, J, . 2003. | Telephone conversation with Jon Stewart, Vice President of Sales | Marine Environmental Partners : - |

# Calcium Hypochlorite




$CaCl_2O_2$ **CAS_#** 7778-54-3

White or yellowish powder with a strong chlorine odor; hygroscopic and corrosive; used for disinfection, color removal, iron and manganese removal, and taste and odor control.

**Other Names** B-Kpowder; bleaching powder; calcium hypochlorite; calcium oxychloride; hypochlorous acid; calcium salt; losatin; calcium hypochloride; chloride of lime; HTH

**Trade_Names** Hyporit; Induclor; Lo-bax; Mildew remover X-14; Perchloron; Pittchlor; Perchloron; Pittabs; Pittclor; Prestochlor; Pulsar; Repak; Stellos; Swim clear

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| crustaceans | LC50: highly toxic | PAN 2004 |
| fish | LC50: highly toxic | PAN 2004 |
| molluscs | LC50: highly toxic | PAN 2004 |
| phytoplankton | EC50: growth, mortality, population, physiology | PAN 2004 |
| zooplankton | LC50: moderately toxic | PAN 2004 |

## Environmental Acceptability

## Shipboard Use

| | | |
|---|---|---|
| Storage | Material must be stowed "on deck only" on a cargo vessel and on a passenger vesel carrying a number of passengers limited to not more than the larger of 25 passengers or one passenger per each 3 m of overal vessel length, but the material is prohibited on passenger vessels in which the limiting number of passengers is exceeded. Stow the material separated from liquid organic materials, powdered metals and their compounds, ammonia compounds, cyanides, and hydrogen peroxide. Shade from radiant heat and stow away from sources of heat. | DOT 2002 |
| Handling | Packing Group II: medium degree of danger presented; oxidizing substance. | DOT 2002 |

## Laws and Regulations

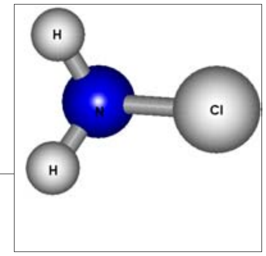
| Country_Region | Regulation | Web site |
|---|---|---|
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/http://www.myregs.com/dotrspa/ |

## Citations



| | | |
|---|---|---|
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |

# Chloramine




$ClH_2N$ **CAS_#** 10599-90-3

Chloramines are a mixture of monochloramine, dichloramine, or nitrogen trichloride. Monochloramine is a colorless and unstable liquid. It is the preferred chloramine species for disinfection because of taste and odor problems with the other species. The CAS number, formula, and molecule structure represent monochloramine.

**Other Names** Chloramide; chloramine/chlorine; chloroamide; chloroammonia; monochloramide; monochloroamine; monochloramine; monochloroammonia

**Trade_Names**

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | Liquid | Health Canada 1996 |
| Physical State | liquid | U.S. EPA 1994 |
| pH | Optimum: 7.5-9.0 for monochloramine formation | Health Canada 1996 |
| pH | At pH 8.5 the rate of its formation reaction reaches maximum. Monochloramine is the only chloramine formed when the pH of ammonia containing water is >8 and the molar ratio of hypochlorite to ammonia is <1. | U.S. EPA 1994 |
| Solubility in water | Soluble | Health Canada 1996 |
| Solubility in water | soluble | U.S. EPA 1994 |
| Stability | Stable in freshwater: halflife of up to 10 days. Less stable in seawater: halflife between 2.5 hours to 2.5 days because of reaction with bromide | Oemcke 1999 |
| Stability | Unstable but more stable than chlorine | U.S. EPA 1999 |
| Inactivation | Bacteria attached to surfaces are difficult to inactivate. | Le Chavalier 1984 |
| Inactivation | Inhibition of proteins and/or protein-mediated processes (i.e., respiration). | U.S. EPA 1999 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| Asiatic clam | for the juvenile: 1.2 to 4.7 mg/L | U.S. EPA 1999 |
| Bacillus subtilis | Monochloramine was able to induce scissions (strand breaks) in both cell-associated-isolated DNA, with the number of breaks increasing with both disinfectant concentration and contact time. | Shih 1976 |
| Burkholderia pseudomallei | Chlorination may be a satisfactory method for controlling colimforms and preventing growth of B. pseudomallei in potable water. | Howard 2003 |
| Cryptosporidium parvum oocysts | Concentration contact time of 9600 min*mg/L removes 1.7 logs | Oemcke 1999 |
| Cryptosporidium parvum oocysts | 80 ppm monochloramine for 90 min achieves 90% inactivation | Korich 1990 |
| E. coli | Given 100 mg/L, 12% reduction with degradation rate of 0.05 mg Cl2/L*hr, 7% reduction with degradation rate of 0.02 mg Cl2/L*hr, 47% reduction with degradation rate of 0.01mg Cl2/L*hr; inactivation rate = 1.0 endotoxin unit (EU)/mL*hr. | Anderson 2003 |
| Enterobacter cloacae | At any given pH, increasing the chlorine-ammonia ratio will increase the inactivation rate. Asa the pH increased from 6 to 8, the rate decreased by a factor of 5-6. | Ward 1984 |
| F. aquatile | Potential sterilization for these organisms using chlorine. Contact times ranging from 1 to 30 minutes with a corresponding concentration range of 12 to 0.5 mg/L led to complete inactivation. | Gilpin 1985 |
| Giardia cysts | For Giardia cysts: 0.5-log, 1.0-log, 1.5-log-2.0-log, 2.5-log and 3.0-log.310 mg-min/L, 615 mg-min/L, 930 mg-min/L, 1230 mg-min/L, 1540 mg-min/L, and 1850 mg-min/L, respectively. | Cowley 1999 |
| Giardia muris cysts | Concentration contact time of 500-3000 min*mg/L removes 2 logs (99%) when temperatures are 5-15 degrees C and pH is 7.5-9. | Oemcke 1999 |
| Klebsiella pnuemoniae | At any given pH, increasing the chlorine-ammonia ratio will increase the inactivation rate. Asa the pH increased from 6 to 8, the rate decreased by a factor of 5-6. | Ward 1984 |
| Legionella bozemanii | Potential sterilization for these organisms using chlorine. Contact times ranging from 1 to 30 minutes with a corresponding concentration range of 12 to 0.5 mg/L led to complete inactivation. | Gilpin 1985 |
| Legionella pneumophilia | Potential sterilization for these organisms using chlorine. Contact times ranging from 1 to 30 minutes with a corresponding concentration range of 12 to 0.5 mg/L led to complete inactivation. | Gilpin 1985 |
| Pseudomonas aeruginosa | Potential sterilization for these organisms using chlorine. Contact times ranging from 1 to 30 minutes with a corresponding concentration range of 12 to 0.5 mg/L led to complete inactivation. | Gilpin 1985 |
| Pseudomonas aeruginosa | At any given pH, increasing the chlorine-ammonia ratio will increase the inactivation rate. Asa the pH increased from 6 to 8, the rate decreased by a factor of 5-6. | Ward 1984 |

| | | |
|---|---|---|
| Viruses | For viruses: 2-log, 3-log, and 4-log;643 mg-min/L, 1067 mg-min/L, and 1491 mg-min/L, respectively. | Cowley 1999 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | Unacceptable: persistance (particularly in freshwater) and toxicity to fish at levels <10 ug/L | Oemcke 1999 |
| Environmental Acceptibility | will not react with organic compounds. | U.S. EPA 1999 |
| Byproducts | In seawater, monobrmamine forms from reaction of monochloramine with bromide | Oemcke 1999 |
| Byproducts | Diachloroacetic acid and other hydrophilic and large molecular organic halides. | U.S. EPA 1999 |
| Inhibitors | strong oxidizing agents such as bromine, chlroine dixoide, iodine, permanganate, hydrogen peroxide, and ozone (the reduced forms do not interfere) | U.S. EPA 1999 |

## Shipboard Use

| | | |
|---|---|---|
| Generation | Can also be produced by adding ammonia to a solution containing free residual chlorine or adding premixed solutions of ammonia and chlorine to water. | Health Canada 1996 |
| Generation | Chloramines are generated by sequential addition of chlorine (hypochlorous acid) and ammonia at a $Cl_2$:$NH_3$ ratio of 3:1 to 5:1. Chloramines must be made on-site. | U.S. EPA 1999 |
| Generation | Chlorine gas + ammonia solid salts or solution at a 5:1 ratio to form monochloramine | Walker 2002 |
| Application | Natural ammonia concentrations will influence dosing. | Health Canada 1996 |
| Application | Normal dose = 1.0-4.0 mg/L; miniumum residual in distribution system = 0.5 mg/L; Prevention of nitrification in distribution system = 2.0 mg/L. | U.S. EPA 1999 |
| Storage | Nitrification potential for storing ammonia solution; chlorine gas | Walker 2002 |
| Handling | Acrid monochloramine and dichloramine fumes can cause burning in eyes and throat, cough, nausea, and vomiting. Personal protective equipment should include appropriate gloves, faceshield, and respirator. | Health Canada 1996 |
| Size | Storage, mixing, and pumping requirements | Walker 2002 |
| Ventilation | Fumes generated when producing monochloramine should be vented. | Health Canada 1996 |
| Maintenance | Dosing equipment and pumps | Health Canada 1996 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East Asian nations | East Asian Seas Action Plan | |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |

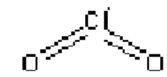
| | | |
|---|---|---|
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations


| | | |
|---|---|---|
| Anderson, WB, CI Mayfield, DG Dixon, PM Huck. 2003. | Endotoxin Inactivation by Selected Drinking Water Treatment Oxidants | Water Research 37: 4553-4560 |
| Blaser, MJ, PF Smith, WL Wang, JC Hoff. 1986. | Inactivation of Campylobacter jejuni by Chlorine and Monochloromine | Applied and Environmental Microbiology 51: 307- |
| Carson, LA, NJ Peterson, MS Favero, SM Aguero. 1978. | Growth characteristics of atypical Mycobacteria in water and their comparative resistance to disinfectants | Applied and Environmental Microbiology 36: 839- |
| Cowley, G, . 1999. | Disinfection with Chlorine Dioxide | Sterling Pulp Chemicals : 1-9 |
| Gilpin, RW, SB Dillon, P Keyser, A Androkites, M Beruke, N Carpendale, J Skorina, J Hurley, AM Kaplan. 1985. | Disinfection of circulating water systems by ultraviolet light and halogenation | Water Research 19: 839- |
| Health Canada, , . 1996. | Chloramines Guideline | Guidelines for Canadian Drinking Water Quality : - |
| Howard, K, TJ Inglish. 2003. | The effect of free chlorine on Burkholderia pseudomallei in potable water | Water Research 37: 4425-4432 |
| Korich, DG, JR Mead, MS Madore, NA Sinclair, CR Sterling. 1990. | Effects of Ozone, Chlorine Dioxide, Chlorine, and Monochloramine on Cryptosporidium parvum Oocyst Viability | Applied and Environmental Microbiology 56: 1423-1428 |
| Le Chavalier, ML, TS Hasseneur, AK Camper, GA McFeters. 1984. | Disinfection of Bacteria Attached to Granular Activated Carbon | Applied and Environmental Microbiology 45: 918- |
| Oemcke, D, . 1999. | The Treatment of Ships' Ballast Water | EcoPorts Monograph Series 18: - |
| Shih, KL, J Lederberg. 1976. | Effects of chloramine on Bacillus subtilis deoxyribonucleic acid | Journal of Bacteriology 125: 934- |
| U.S. EPA, , . 1994. | Drinking Water Criteria Document for Chloramines | National Center for Environmental Assessment ECAO-CIN-D002 : - |
| U.S. EPA, , . 1999. | Alternative Disinfectants and Oxidants Guidance | EPA Report 815-R-99-014 : - |
| Walker, I, . 2002. | Chloramination -- Future Best Practice for the Water Industry? | www.wrcplc.co.uk/downloads : - |
| Ward, NR, RL Wolfe, BH Olsen. 1984. | Effects of pH, application, technique, and chlorine-to-nitrogen ratio on disinfectant activity of inorganic chloramines with pure culture bacteria | Applied and Environmental Microbiology 48: 508- |

# Chlorine Dioxide

$ClO_2$ **CAS_#** 10049-04-4




A gas used as a powerful biocide, disinfectant agent, and oxidizer. It is produced and used on location. The liquid and solid forms of chlorine dioxide are extremely unstable and explosive.

**Other Names** Chlorine oxide; chlorine peroxide; anthium dioxcide; chlorine (IV) oxide; chloroperoxyl; chloryl radical; alcide

**Trade_Names** doxcide 50

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | solid | Raytec Corp 2004 |
| Physical State | gas | U.S. EPA 1999 |
| pH | affects are noted for the generation of the disinfectant but does not influence biocidal properties | U.S. EPA 1999 |
| Solubility in water | high, particularly in chilled water. Remains in solution as a dissolved gas. | U.S. EPA 1999 |
| Stability | Unreactive in its dry form | Raytec Corp 2004 |
| Stability | Decomposes in sunlight. Stable in dilute solution in a closed container in absence of light. Reacts violently with reducing agents and therefore cannot be transported. | U.S. EPA 1999 |
| Inactivation | chlorine dioxide may react with amino acids to alter viral capsid proteins or RNA to impair RNA synthesis. Also can effect physiological functions such as increasing permeability of outer membrane. | U.S. EPA 1999 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| crustaceans | not acutely toxic | PAN 2004 |
| Cryptosporidium | For 1-log inactivation, CT values range 100-120 mg-min/L at temp between 5-15 deg C and pH between 6.5-8.5. Not effective at low temps. | Cowley 1999 |
| Cryptosporidium parvum | Approximately 90% inactivation of oocysts after 1 hour of exposure to 1.3 mg/L (using infectivity method). | Korich 1990 |
| Cryptosporidium parvum | 30 minute contact time with 0.22 mg/L reduced oocyst infectivity; 3-log inactivation with 2.7 and 3.3 mg/L chlorine dioxide for contact times of 120 minutes at pH of 8 and temp of 22 deg C. | U.S. EPA 1999 |
| Dreissena polymorpha | 70% mortality with 5 mg/L in flow-through cooling water systems | Rigby 2001 |
| E. coli and B. anthracis | dosages in the range of 1 - 5 mg/L | U.S. EPA 1999 |
| fish | not acutely toxic | PAN 2004 |
| Giardia cysts | 0.5 log inactivation: 4 mg-min/L; 1.0 log inactivation: 7.7 mg-min/L; 1.5 log inactivation: 12 mg-min/L; 2.0 log inactivation: 15 mg-min/L; 2.5 log inactivation: 19 mg-min/L; and 3 log inactivation: 23 mg-min/L at 10 deg C and pH = 6-9. | Cowley 1999 |
| Giardia cysts | 60 minute contact time, doses from 1.5 to 2 mg/L provide a 3-log inactivation at 1 deg C and pHs of 6 and 9. | U.S. EPA 1999 |
| molluscs | not acutely toxic | PAN 2004 |
| total coliform and f2 coliphage virus in sewage | initial chlorine dioxide residuals between 0.85 and 0.95 mg/L resulted in 2.8-log inactivation of the total coliform and an average 4.4-log inactivatio of the f2 coliphage over a contact time of 240 minutes. | U.S. EPA 1999 |
| Viruses | 2-log inactivation: 4.2 mg-min/L; 3-log inactivation 12.8 mg-min/L; 4-log inactivation: 25.1 mg-min/L | Cowley 1999 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | does not react with organic matter or bromides | Cowley 1999 |
| Environmental Acceptibility | More effective than chlorine and chloramines for inactivation of viruses, cryptosporidium, and giardia. May enhance clarification process. | U.S. EPA 1999 |
| Byproducts | No toxic products formed | Cowley 1999 |
| Byproducts | Fewer by-products are generated using the electrochemical method of production. | Cowley 2000 |
| Byproducts | Chlorine dioxide can produce two major by-products: chlorate and chlorite. Newer generators do not produce chlorate. | Oemcke 1999 |
| Byproducts | Reaction of hypochlorous acid with sodium chlorite is sodium hydroxide. Chlorate also undesirable byproduct. Chlorine dioxide reacts with the soluble forms of iron and manganese to form precipitates. | U.S. EPA 1999 |
| Inhibitors | pH and temperature | Cowley 1999 |

| | | |
|---|---|---|
| Inhibitors | high pH slows formation of chlroine dioxide and impels less efficient chlorate-forming reactions. | U.S. EPA 1999 |
| Effectiveness Factor | Perstraction membrane isolates the reaction system and passes only ClO2 and other gasses which produces a high quality product (high conversion efficiency). | Cowley 2000 |
| Effectiveness Factor | Humidity or moisture in the air can start the reaction between the chlorite salt and the proprietary activators impregnated on the solid substrate. | Raytec Corp 2004 |
| Effectiveness Factor | Disinfection effeciency decreases as temp decreases. Suspended matter and pathogen aggregation affect the disinfection efficiency. More suspended matter means less efficiency. | U.S. EPA 1999 |

## Shipboard Use

| | | |
|---|---|---|
| Generation | Produced onsite with an electrochemical cell and sodium chlorite; other methods include mixing chlorine gas and sodium chlorite or hydrochloric acid and sodium chlorite or hydrochloric acid, sodium hypochlorite, and sodium chlorite on site. | Cowley 1999 |
| Generation | Electrolytic process that converts sodium chlorite solution to chlorine dioxide. | Halox Technologies 2003 |
| Generation | When the dmClO2 comes in contact with water or is exposed to moisture a reaction occurs between the chlorite salts and the proprietary activators that are impregnated on the zeolitic substrate. | Raytec Corp 2004 |
| Generation | Common precursor feedstock is sodium chlorite reacting with gaseous chlorine, hypochlorous acid, or hydrochloric acid. May also use sodium chlorate and hydrogen peroxide and concentrated sulfuric acid. Generally, few DBPs. | U.S. EPA 1999 |
| Application | Dosed on site | Cowley 1999 |
| Application | Requires softened, potable feedwater (~1900 gal/day at max generation). | Halox Technologies 2003 |
| Application | If dosed during ballasting it can be expected to decline to low levels before release. | Oemcke 1999 |
| Storage | Requirements for sodium chlorite solution (25% w/w), dosing tank, and electrochemical cassettes (6-month shelf-life). | Halox Technologies 2003 |
| Storage | Loose powder or sachets must be kept dry to eliminate activation and production of ClO2. | Raytec Corp 2004 |
| Storage | Cannot be compressed or stored as a gas. | U.S. EPA 1999 |
| Handling | Can lead to production of noxious odors | U.S. EPA 1999 |
| Size | 2'x 4' for generating equip + dosing tank + storage. | Halox Technologies 2003 |
| Corrosivity | Negligible | Raytec Corp 2004 |
| Corrosivity | Corrosive effects on steel | Rigby 2001 |
| Power Requirements | ~ 4 kW operating at max capacity (5.2 lbs can be generated per day with Halox 2000 system with 4 cassettes). | Halox Technologies 2003 |
| Ventilation | Hydrogen gas needs to be vented from cathode. | Cowley 2000 |
| Maintenance | Every 2000 hours of operation. | Halox Technologies 2003 |
| Limits | Forbidden from transporting as material; must be generated onsite. | DOT 2002 |
| Limits | Catholyte product waste stream | Halox Technologies 2003 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East Asian nations | East Asian Seas Action Plan | |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| European Union | Existing Substances Regulation 793/93/EEC | http://ecb.jrc.it/Legislation/1993R0793EC.pdf |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |

| | | |
|---|---|---|
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |
| USA | Occupational Safety and Health Act | http://www4.law.cornell.edu/uscode/29/ch15.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations

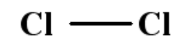

| | | |
|---|---|---|
| Cowley, G, Sterling Pulp Chemicals. 1999. | Disinfection with chlorine dioxide | http://clo2.com/water/Dis_paper/Disinfection_Paper.htm : - |
| Cowley, G, T Znajewski. 2000. | ECF™ Technology: The Chlorine Dioxide Generation System of the Future | Sterling Pulp Chemicals, http://clo2.com/reading/publications/pub.html : - |
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| Fisher, DJ, DT Burton, LT Yonkos, SD Turley, GP Ziegler, BS Turley. 2002. | Derivation of Acute Ecological Risk Criteria for Chlorite in Freshwater Ecosystems | Water Research 37: 4359-4368 |
| Halox Technologies, , . 2003. | Halox Technical Data Sheets | www.haloxtech.com : - |
| Korich, DG, JR Mead, MS Madore, NA Sinclair, CR Sterling. 1990. | Effects of Ozone, Chlorine Dioxide, Chlorine, and Monochloramine on Cryptosporidium parvum Oocyst Viability | Applied and Environmental Microbiology 56: 1423-1428 |
| Oemcke, D, . 1999. | The Treatment of Ships' Ballast Water | EcoPorts Monograph Series 18: - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Raytec Corp, , . 2004. | dmClO2 Overview | Raytec Corporation, |

| | | |
|---|---|---|
| | | http://www.raytecnet.com/ : - |
| Rigby, G, AH Taylor. 2001. | Ballast Water Treatment to Minimise the Risks of Introducing Nonindigenous Marine Organisms into Australian Ports | Ballast Water Report Series : - |
| U.S. EPA, , . 1999. | Alternative Disinfectants and Oxidants Guidance Manual | : - |

# Chlorine

$Cl_2$ **CAS_#** 7782-50-5

A highly reactive gas used to remove color and disinfect water.



**Other Names** Bertholite, warfare gas, chloor (Dutch), chlore (French), chlor (German)

**Trade_Names**

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | greenish-yellow, diatomic gas | Hazardous Substances Data Bank 2004 |
| pH | persists as an element only at a very low pH (less than 2), and at the higher pH found in living tissue it is rapidly converted into hypochlorous acid. | Hazardous Substances Data Bank 2004 |
| Specific gravity | 1.564 | Hazardous Substances Data Bank 2004 |
| Solubility in water | Soluble in water at 25 deg C, more soluble in alkalies | Hazardous Substances Data Bank 2004 |
| Inactivation | Bacteria and protozoa: breaches the cell wall and attacks nucleus; Viruses: attacks the DNA | Bolek 2003 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| annelida | LC50: moderately toxic | PAN 2004 |
| Baetis harrisoni | 24 h LC50 - 11.2 and 10.1 ug/L; 48 h LC50 - 5.0 and 6.5 ug/L; 96 h LC50 - 4.1 and 4.8 ug/L. | Williams 2003 |
| Centroptilium spp. | 24 h LC 50 - 71 ug/l, 46 ug/l (8 h), and 502 ug/l (8 h); 48 h LC50 - 27 and 93 ug/L; | Williams 2003 |
| Ceriodaphnia dubia | 24 h LC50 - 5 ug/L (hypochlorus acid), 6 ug/L (hypochlorite ion), 16 ug/L (monochloramine), and 27 ug/L (dichloramine). | Williams 2003 |
| crustaceans | LC50: highly toxic | PAN 2004 |
| D. polymorpha (freshwater mussel) | continuous 1 mg/L mortality in 588 hours | Rajagopal 2003 |
| Daphnia magna | 24 h LC50 140 ug/L; 48 h LC50 - 116 ug/L | Williams 2003 |
| Daphnia magna | 48 h LC 50 - 45 ug/L and 17 ug/L | Williams 2003 |
| fish | LC50: highly toxic | PAN 2004 |
| Giardia cysts | 17 mg-min/L, 35 mg-min/L, 52 mg-min/L, 69 mg-min/L, 87 mg-min/L, and 104 mg-min/L, respectively. | Cowley 1999 |
| Hexagenia spp | 48 h LC 50 - 357 ug/L | Williams 2003 |
| M. Eduli (marine mussel) | continuous 1 mg/L mortality in = 966 hour | Rajagopal 2003 |
| M. Leucophaeata (brakish water) | continuous 1 mg/L mortality within 1104 hours | Rajagopal 2003 |
| Micororganisms, ghiardia, cryptosporidium | Depends on what is in the water. Ranges from 0.5 ppm to 50 ppm. | Bolek 2003 |
| molluscs | LC50: highly toxic | PAN 2004 |
| Pteronarcys spp | 96 h LC50 400 ug/L | Williams 2003 |
| Stenonema ithaca | 96 h LC50 - 102 ug/L | Williams 2003 |
| Viruses | For Giardia cysts: 0.5-log, 1.0-log, 1.5-log, 2.0-log, 2.5-log, and 3.0-log.for viruses: 2-log, 3-log, and 4-log;3 mg-min/L, 4 mg-min/L, and 6 mg-min/L, respectively. | Cowley 1999 |
| zooplankton | LC50: highly toxic | PAN 2004 |

**Environmental Acceptability**

| | | |
|---|---|---|
| Byproducts | Chlorine will produce trihalomethanes, haloacetic acid | Bolek 2003 |
| Effectiveness Factor | The time taken for 100% mortality of mussels decreased with increasing chlorine concentration. Chlorine serves as an excellent biocides for controlling biofouling in cooling water systems, its use is restricted due to environmental considerations, Efficacy of chlorine as an antifoulant depends on various parameters, most importantly resiudal levels of chlorine and contact time. | Rajagopal 2003 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | Material must be stowed "on deck only" on a cargo vessel and on a passenger vesel carrying a number of passengers limited to not more than the larger of 25 passengers or one passenger per each 3 m of overal vessel length, but the material is prohibited on passenger vessels in which the limiting number of passengers is exceeded. This material must also be stowed clear of living quarters, and separated from acetylene, ammonia, diborane, hydrogen, and radioactive material. | DOT 2002 |
| Corrosivity | Chlorine can be corrosive. System uses approximately 0.4-0.8% chlorine in the solution to prevent corrosion. | Bolek 2003 |
| Power Requirements | Small system: 220V AC Large system: 480V AC | Bolek 2003 |
| Ventilation | Poisonous gas and must be stowed on deck. | DOT 2002 |
| Maintenance | Periodic preventative maintenance, loading brine tank, keeping recording logs | Bolek 2003 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Canada | Canada Shipping Act - Part (XV): Pollutant Substances Regulations (CRC, c. 1458) | http://www.tc.gc.ca/acts-regulations/GENERAL/C/csa/regulations/050/csa052/csa52.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East Asian nations | East Asian Seas Action Plan | |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| European Union | Existing Substances Regulation 793/93/EEC | http://ecb.jrc.it/Legislation/1993R0793EC.pdf |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |

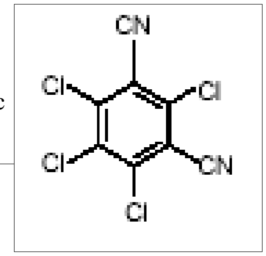
| | | |
|---|---|---|
| USA | Occupational Safety and Health Act | http://www4.law.cornell.edu/uscode/29/ch15.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations


| | | |
|---|---|---|
| Anderson, WB, CI Mayfield, DG Dixon, PM Huck. 2003. | Endotoxin Inactivation by Selected Drinking Waer Treatment Oxidants | Water Research 37: 4553-4560 |
| Bolek, K, . 2003. | Telephone conversation with Katie Bolek, Marketing Manager | Miox Corporation : - |
| Cowley, G, . 1999. | Disinfection with chlorine dioxide | Sterling Pulp Chemicals : 1-9 |
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| Dychdala, GR, . 1991. | Chlorine and Chlorine Compounds | Disinfection, Sterilization, and Preservation. S.S. Block (Ed.) : - |
| Hazardous Substances Data Bank, , . 2004. | Chlorine | National Library of Medicine Toxnet System : - |
| Korich, DG, JR Mead, MS Madore, NA Sinclair, CR Sterling. 1990. | Effects of Ozone, Chlorine Dioxide, Chlorine, and Monochloramine on Cryptosporidium parvum Oocyst Viability | Applied and Environmental Microbiology 56: 1423-1428 |
| Oemcke, D, . 1999. | The Treatment of Ships' Ballast Water | EcoPorts Monograph Series 18: - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Rajagopal, S, GV Velde, M VDG Gaag. HA Jenner. 2003. | How Effective is intermittent chlorination to control adult mussel fouling in cooling water system | Water Research 37: 329-338 |
| Rajagopal, S, Van der Velde, G., and H, A. Jenner. 2002. | Effects of low-level chlorination on zebra mussel, Dreissena polymorpha | Water Research 36: 3029-3034 |
| Williams, ML, CG Palmer and AK Gordon. 2003. | Riverine macroinvertebrate responses to chlorine and chlorinated sewage effluents - Acute chlorine tolerances of Baetis harrisoni (Ephemeroptera) from | Water SA 29: 483- |

# Chlorothalonil

$C_8Cl_4N_2$ **CAS_#** 1897-45-6




White crystalline solid, used as a fungicide effective against a broad range of plant pathogens attacking many agronomic and vegetable crops. Also used as a preservative in paints and adhesives.

**Other Names** 1,3-Benzenedicarbonitrile, 2,4,5,6-tetrachloro-; 2,4,5,6-Tetrachloroisophthalonitrile;

**Trade_Names** Daconil 2787; Bravo; Sweep; Vanox

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Solubility in water | IN WATER @ ROOM TEMP 0.6 PPM; Solubility (25 deg C): 0.6 mg/kg water | Hazardous Substances Data Bank 2004 |
| Stability | will readily biodegrade under aerobic and anaerobic conditions in aquatic ecosystems; DOES NOT HYDROLYZE IN MODERATE ALKALINE OR ACIDIC MEDIA | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| amphibians | LC50: highly toxic | PAN 2004 |
| clams | LC50 Mya arenaria clams 35.0 5.9 mg/l/96 hr /Bravo 500; conditions of bioassay not specified; LC50 Mytilus edulis (blue mussels) 5.9 mg/l/96 hr; conditions of bioassay not specified; LC50 Rainbow trout 76 ug/l/96 hr /Technical chlorothalonil; conditions of bioassay not specified | Hazardous Substances Data Bank 2004 |
| crustaceans | LC50: very highly toxic | PAN 2004 |
| Fish | LC50: very highly toxic | PAN 2004 |
| fish, aquatic invertebrates | 47-84 ppb is highly toxic to fish; may affect fish populations at low levels (3 - 6.5 ppb). aquatic invertebrates and may affect their reproduction at low conc (> 79 ppb) | Hazardous Substances Data Bank 2004 |
| molluscs | LC50: slightly toxic | PAN 2004 |
| phytoplankton | EC50: accumulation, population | PAN 2004 |
| zooplankton | LC50: moderately toxic | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | Half-life of 38.1 days in aqueous media at pH 9; Koc value of 1,800(6) indicates adsorption from the water column to sediment and suspended material may occur | Hazardous Substances Data Bank 2004 |
| Environmental Acceptibility | anaerobic half life <0.5 days | Thomas 2003 |
| Byproducts | At pH 9, chlorothalonil in water may hydrolyze to 4-hydroxy-2,5,6-trichloro-isophthalonitrile and 3-cyano-2,4,5,6-tetrachlorobenzamide; | Hazardous Substances Data Bank 2004 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | Keep in cool, dry, ventilated place | Hazardous Substances Data Bank 2004 |
| Handling | Use gloves, apron, rubber or plastic boots; use mask for powders | Hazardous Substances Data Bank 2004 |
| Corrosivity | Non-corrosive | Hazardous Substances Data Bank 2004 |
| Ventilation | required | Hazardous Substances Data Bank 2004 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| | East Asian Seas Action Plan | |
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |

| | | |
|---|---|---|
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean Region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations


| | | |
|---|---|---|
| Albanis, TA, DA Lambropoulou, VA Sakkas, IK Konstantinou. 2002. | Antifouling Paint Booster Biocide Contamination in Greek Marine Sediments | Chemosphere 48: 475-485 |
| Hazardous Substances Data Bank, , . 2004. | Chlorothalonil | National Library of Medicine Toxnet System : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Thomas, KV, M McHugh, M Hilton, M Waldock.. 2003. | Increased persistence of antifouling paint biocides when associated with paint particles | Environmental Pollution 123: 153-161 |

# Copper Ions

$Cu^{2+}$ **CAS_#** 15721-63-8

Algicide, toxic to heterotrophic bacteria in aquatic environments and has been used to control poliovirus; electrolytically generated

**Other Names**

**Trade_Names**

**$Cu^{2+}$**

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | aqueous solution | Hazardous Substances Data Bank 2004 |
| Inactivation | The presence of the high CU2+ concentration in the culture medium induced the morphological changes of the organism. | Gardea-Torresdey 1997 |
| Inactivation | decrease in photosynthesis activity | Gustavson 1995 |
| Inactivation | Neither bacterial nor phytoplankton viability appeared to be affected. Some influence on viability of zooplankton and dinoflagellate cysts. Effects may have resulted from inordinately high copper concentrations. | Rigby 2001 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| | Freshwater: 33% effective at 167 ppb. Seawater (simulated): 70% effective at 68 ppb. | Gracki 2002 |
| amphibians | LC50: very highly toxic | PAN 2004 |
| crustaceans | LC50: highly toxic | PAN 2004 |
| echnoderms | LC50: very highly toxic | PAN 2004 |
| fish | LC50: moderately toxic | PAN 2004 |
| Freshwater crayfish | LC50: 0.83 mg/L for 96 hours; 4.07 mg/L for 24 hours (intermoult adult male) | Oemcke 1999 |
| Gymnodinium catenatum cysts | 200 mg/L was ineffective for inactivation | Oemcke 1999 |
| marine benthic community | LC50: highly toxic | PAN 2004 |
| Microalgal communities | Concentration in the enclosure area: the copper concentration varied from 0.013 to 0.007 uM (low Cu), 0.087 to 0.032 (medium Cu), 0.205 to 0.157 (high Cu). A decrease in photosynthesis activity was observed when exposed to low and medium Cu, a drop of about 50%. For high Cu, a drop of less than 10%. The photosynthesis activity is not affected by the highest Cu anymore. | Gustavson 1995 |
| molluscs | LC50: moderately toxic | PAN 2004 |
| Mucor rouxii | | Gardea-Torresdey 1997 |
| nematodes and flatworms | LC50: moderately toxic | PAN 2004 |
| Oocytis nephrocytiodes | A 5uM copper treatment increased the population from less than 1% in the control to 56%. | Soldo 2000 |
| phytoplankton | LC50: very highly toxic | PAN 2004 |
| zooplankton | LC50: very highly toxic | PAN 2004 |

**Environmental Acceptability**

| | | |
|---|---|---|
| Environmental Acceptibility | Unsuitable: toxicity to fish if discharged at doses needed for effective inactivation. | Gracki 2002 |
| Environmental Acceptibility | Communities that were exposed to copper also showed an increased co-tolerance to zinc, nickel, and silver. | Soldo 2000 |
| Byproducts | Reacts with phosphates to form insoluble precipitate. It also forms complexes and chelates with ammonia, humic acid, and other organics reducing its bioavailability. | Oemcke 1999 |
| Inhibitors | Presence of sediments (settled or suspended) reduces efficacy of copper as a biocide. | Gracki 2002 |
| Effectiveness Factor | Copper reacts with dissolved organic matter; simulated seawater did not have proper amounts of solutes. | Gracki 2002 |
| Effectiveness Factor | > 2 days: Low concentration of Cu--No effect on biomass, photosynthesis activity, or short-term tolerance. Small change in species composition.<br>High concentration of Cu--There is a very strong reduction in biomass and photosynthesis activity. Increased short-term tolerance. Strong change in species composition.<br>2-14 days: Low concentration of Cu-- There is a decrease in photosynthesis activity.<br>High concentration of Cu--Continuation of the effects seen during the first 2 days.<br>14-20 days: Low concentration of Cu--Increased tolerance for copper in the short-term test. Co-tolerance for zinc.<br>High concentration of Cu--Increasing biomass and photosynthesis activity. High tolerance for | Gustavson 1995 |

| | | |
|---|---|---|
| | copper and co-tolerance for zinc. | |
| Effectiveness Factor | After 12 weeks of copper exposure to the freshwater periphyton communities, it was found that there was a change in the distribution of algal classes from a community dominated by Cyanophyceae to one dominated by Chlorophyta.<br><br>Periphyton communities subjected to long-term exposure at different concentrations did not differ significantly in the photosynthesis rate. | Soldo 2000 |
| Effectiveness Factor | Copper exhibits antifouling activity against organisms such as barnacles, tube worms, and the majority of algal fouling species. However, several algal species, such as Enteromorpha spp., Ectocarpus spp., Achnanthes spp., show physiological tolerance to copper. | Voulvoulis 2002 |

## Shipboard Use

| | | |
|---|---|---|
| Generation | Electrically generated Cu ions | Rigby 2001 |
| Storage | Solid form can be stowed "on deck" or "under deck", but clear of living quarters. | DOT 2002 |
| Corrosivity | 0.02-0.05 ppm can cause corrosion to aluminum. | Gracki 2002 |
| Ventilation | Poison | DOT 2002 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| | East Asian Seas Action Plan | |
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |

| | | |
|---|---|---|
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean Region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations


| | | |
|---|---|---|
| Abad, FX, RM Pinto, JM Diez, and A Bosch. 1994. | Disinfection of Human Enteric Viruses in Water by Copper and Silver Combination with Low Levels of Chlorine | Applied and Environmental Microbiology : 2377-2383 |
| Boxall, ABA, SD Comber, AU Conrad, J Howcroft, N Zaman. 2000. | Inputs, monitoring, and fate modelling of antifouling biocides in UK estuaries | Marine Pollution Bulletin 40: 898-905 |
| Cabral, JP, . 2002. | Differential sensitivity of four lobaria lichens to copper in vitro | Environmental Toxicology and Chemistry 21: 2468-2476 |
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| Gardea-Torresdey, JL, I Cano-Aguilera, R Webb, F. Gutierrez-Corona. 1997. | Enhanced copper adsorption and morphological alterations of cells of copper-stressed Mucor rouxii | Environmental Toxicology and Chemistry 16: 435-441 |
| Gracki, JA, RA Everett, H Hack, PF Landrum, DT Long, BJ Premo, SC Raaymakers, GA Stapleton, KG Harrison. 2002. | Critical Review of a Ballast Water Biocides Treatment Demonstration Project Using Copper and Sodium Hypochlorite | Michigan Environmental Science Board, Lansing : - |
| Gustavson, K, SA Wangberg. 1995. | Tolerance induction and succession in microalgae communities exposed to copper and atrazine | Aquatic Toxicology 32: 283-302 |
| Haslbeck, JS, . 2003. | Measurement of copper release rates from antifouling paint under laboratory and in-situ conditions: implications for loading estimation to marine wate | Marine Pollution Bulletin 46: 763-779 |
| Hazardous Substances Data Bank, , . 2004. | Copper Compunds | National Library of Medicine Toxnet System : - |
| Oemcke, D, . 1999. | The Treatment of Ships' Ballast Water | EcoPorts Monograph Series 18: - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Rigby, G, AH Taylor. 2001. | Ballast Water Treatment to Minimise the Risks of Introducing Nonindigenous Marine Organisms into Australian Ports | Ballast Water Report Series : - |
| Soldo, D, R Behra. 2000. | Long-term effects of copper on the structure of freshwater periphyton communities and their tolerance to copper, zinc, nickel, and silver | Aquatic Toxicology 47: 181-189 |
| Voulvoulis, N, MD Scrimshaw, JN Lester. 2002. | Comparative environmental assessment of biocides used in anitfouling paints | Chemosphere 47: 789-795 |

# Copper Sulfate

$CuSO_4 \bullet 5H_20$ **CAS_#** 7758-99-8

Available as a wettable powder or in liquid concentrate form.

**Other Names** Blue copper AS; Blue vitriol; Bluestone; copper sulfate (pentahydrate), copper sulphate pentahydrate; Copper(II)sulfate; Cupric Sulfate

**Trade_Names** Blue Vitriol

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | grayish white greenish white rhombic crystals | Hazardous Substances Data Bank 2004 |
| Specific gravity | 3.6 | Hazardous Substances Data Bank 2004 |
| Solubility in water | 243 g/l at 0 deg C; 75.4 g/100 cc water at 100 deg C | Hazardous Substances Data Bank 2004 |
| Stability | Aquatic fate highly dependent on pH, concentration of organic matter, iron and manganese oxide and hardness of water. | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| amphibians | highly toxic | PAN 2004 |
| crustaceans | slightly toxic | PAN 2004 |
| fish | moderately toxic | PAN 2004 |
| molluscs | very highly toxic | PAN 2004 |
| nematodes and flatworms | very highly toxic | PAN 2004 |
| zooplankton | slightly toxic | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | Soluble copper compounds sorb strongly to suspended particles. | Hazardous Substances Data Bank 2004 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | Keep tightly closed | Hazardous Substances Data Bank 2004 |
| Handling | strong irritant; wear gloves, boots, and goggles. | Hazardous Substances Data Bank 2004 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |

## Citations



| | | |
|---|---|---|
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| Hazardous Substances Data Bank, , . 2004. | Copper Sulfate | National Library of Medicine Toxnet System : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |

# Cupric Ascorbate

**CAS_#** 3333-33-3

**Other Names**

**Trade_Names**

**Environmental Acceptability**

**Shipboard Use**

**Laws and Regulations**

| Country_Region | Regulation | Web site |
|---|---|---|
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East Asian nations | East Asian Seas Action Plan | |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |

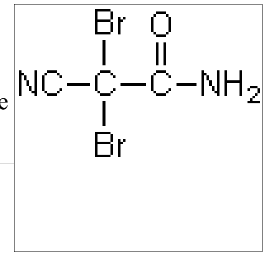
| | | |
|---|---|---|
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

### Citations


| | | |
|---|---|---|
| Sagripanti, J, A Bonifacino. 1996. | Comparative Sporicidal Effects of Liquid Chemical Agents | Applied Environmental Microbiology 62: 545-551 |

# Dibromonitrilopropionamide (DBNPA)

$C_3H_2Br_2N_2O$ **CAS_#** 10222-01-2




Algicide, bactericide, fungicide, and preservative used in paper industry and water treatment. Available as a slow-release solid or as a liquid solution.

**Other Names** 2,2-dibromo-3-nitrilopropionamide; 2,2-Dibromo -2-carbamoylacetonitrile; 2,2-dibromo-3-nitrilopropionamide, DBNPA; dibromocyanoacetamide

**Trade_Names** Acetamide; Slimicide 508; XD-1603, XD-7287L Antimicrobial

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | liquid or solid | AMSA, Inc 2004 |
| pH | 6.61 in 0.01% aqueous solution at 25 deg C | Hazardous Substances Data Bank 2004 |
| Solubility in water | 15,000 mg/l.; log Kow= 0.80 @ pH 7; 0.795 @ pH 5; 0.82 @ pH 9.0 | Hazardous Substances Data Bank 2004 |
| Stability | quickly degrades to ammonia and bromide ion | AMSA, Inc 2004 |
| Stability | Stable under normal conditions, decomposition accelerated by light & heat. | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| crustaceans | LC50: moderately toxic | PAN 2004 |
| fish | LC50: moderately toxic | PAN 2004 |
| molluscs | EC50: intoxication | PAN 2004 |
| zooplankton | LC50: highly toxic | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Byproducts | ammonia and bromide ion | AMSA, Inc 2004 |
| Byproducts | When heated to decomposition it emits very toxic fumes of bromine & nitrogen oxides. | Hazardous Substances Data Bank 2004 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | non-explosive, non-combustible; incompatible with bases, reducing substances & nucleophiles | Hazardous Substances Data Bank 2004 |
| Corrosivity | liquid is an oxidizer because of hypobromous acid in formulation | AMSA, Inc 2004 |
| Corrosivity | Corrosive to mild steel, iron and aluminum | Hazardous Substances Data Bank 2004 |

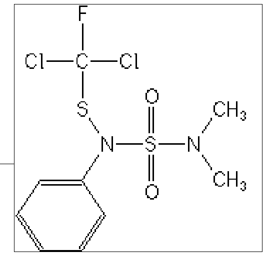
## Laws and Regulations

## Citations


| | | |
|---|---|---|
| AMSA, Inc, , . 2004. | DBNPA Overview | http://www.amsainc.com/prod-dbnpa-overview.asp : - |
| Hazardous Substances Data Bank, , . 2004. | DBNPA | National Library of Medicine Toxnet System : - |
| Klaine, SJ, Cobb, G.P., Dickerson, R.L., Dixon, K.R., Kendall, R.J., Smith, E.E., and K.R. Solomon. 1996. | An ecological risk assessment for the use of the biocide, dibromonitrilopropionamide (DBNPA), in industrial cooling systems | Environmental Toxicology and Chemistry 15: 21-30 |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |

# Dichlofluanid

$C_9H_{11}Cl_2FN_2O_2S_2$ **CAS_#** 1085-98-9



Fungicide. Available in liquid form.

**Other Names** 1,1-dichloro-N-[(dimethylamino)sulfonyl]-1-fluoro-N-phenylmethanesulfenamide; N-dichlorofluoromethylthio-N′,N′-dimethyl-N-phenylsulfamide; Aniline; dichlofluanide , N,N-Dimethyl-N'-phenyl-N'-((fluorodichloromethyl)thio)sulfamide; N-(Dichlorofluoromethylthio)-N',N'-dimethyl-N-phenylsulfamide; Sulfamide; N-((dichlorofluoromethyl)thio)-N',N'-dimethyl-N-phenyl-

**Trade_Names** Bay 47531; Bay KUE 13032C; Dichlofluanide (France) , Diclofluanida; Diklofluanid; Elvaron; Euparen; Euparene; KUE 13032C

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Solubility in water | 1.3 mg/L in water | Hazardous Substances Data Bank 2004 |
| Stability | degrades faster at higher pH (pH=9); in alkaline medium, DT50 at 22 deg C >15 days at pH =4; in alkaline medium, DT50 at 22 deg C >18 hours at pH =7 and <10 minutes at pH of 9 | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| crustaceans | EC50: behavior, mortality | PAN 2004 |
| fish | EC50: mortality | PAN 2004 |
| fungi | not provided | Hazardous Substances Data Bank 2004 |
| molluscs | EC50: growth, mortality | PAN 2004 |
| molluscs | LC50: moderately toxic | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | may adsorb to suspended solids and sediment in water, Koc of 1100 | Hazardous Substances Data Bank 2004 |
| Environmental Acceptibility | anaerobic half life <0.5 days. An increase half life of 1.4 days when is introduced as an antifouling paint. | Thomas 2003 |
| Byproducts | in alkaline solution: N',N'-dimethyl-N-phenylsulphamide | Hazardous Substances Data Bank 2004 |
| Byproducts | degrades will transform to N,N-dimethyl-N'-phenyl-Sulfamide (DMSA) with m-dichlorofluoromethylthion-aniline, aniline, and dichlorofluoromethane also being formed. | Thomas 2003 |
| Inhibitors | adsorption to suspended solids and pH | Hazardous Substances Data Bank 2004 |
| Effectiveness Factor | alkaline conditions | Hazardous Substances Data Bank 2004 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | stable in storage for at least one year when worked up with small quantity of inert material; practically nonvolatile | Hazardous Substances Data Bank 2004 |
| Handling | avoid contact with eyes and skin and inhalation. | Hazardous Substances Data Bank 2004 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| | East Asian Seas Action Plan | |
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the | http://www.unepmap.gr/pdf/dumping |

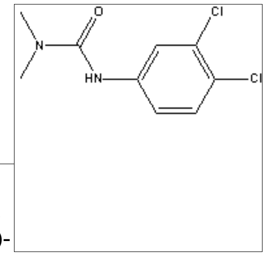
| | | |
|---|---|---|
| | Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | .pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean Region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations


| | | |
|---|---|---|
| Albanis, TA, DA Lambropoulou, VA Sakkas, IK Konstantinou. 2002. | Antifouling Paint Booster Biocide Contamination in Greek Marine Sediments | Chemosphere 48: 475-485 |
| Hazardous Substances Data Bank, , . 2004. | Dichlofluanid | National Library of Medicine Toxnet System : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Thomas, KV, M McHugh, M Hilton, M Waldock. 2003. | Increased persistence of antifouling paint biocides when associated with paint particles | Environmental Pollution 123: 153-161 |

# Diuron

$C_6H_3Cl_2NHCON(CH_3)_2$ **CAS_#** 330-54-1




Herbicide. Available as a solid (white, odorless, crystalline) or a liquid solution.

**Other Names** 1,1-Dimethyl-3-(3,4-Dichlorophenyl)urea; 1-(3,4-Dichlorophenyl)-3,3-dimethylurea; 3-(3,4-Dichlorophenyl)-1,1-Dimethylurea; M Velpar; Aguron; Diater; Di-on; Diurex; Diuron; Diuron ; Diuron 4L; Diuron 80; Cekiuron; Crisuron; Dailon; DCMU; DMU; Drexel diuron 4L; N'-(3,4-Dichlorophenyl)-N,N-Dimethylurea;

**Trade_Names** Direx 4L; Direx 80W; Dynex; Karmex; Karmex 80W; Karmex DL; Unidron; Urox D; Vonduron; Xarmex, Krovar

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Solubility in water | n water, 36.4 mg/l @ 25 deg C | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| algae | reduced by 92% filamentous algae or common macrophytes (Potamogeton foliosus, Potamogeton pusillus, Najas flexilis, Najas gracillima, Ceratophyllum demorsum) during a study on twenty 3.048 m diameter pools. All the pools were stocked with fingerling bluegills (Lepomis macrochirus) and golden shiner (Notemigonus crysoleucas), which the diuron did not influence | Hazardous Substances Data Bank 2004 |
| amphibians | LC50: slightly toxic | PAN 2004 |
| ASELLUS | LC50 15.5 MG/L/96 HR (95% CONFIDENCE LIMIT 7.2-33.4 MG/L), @ 15 DEG C, MATURE /95% TECHNICAL GRADE/. STATIC BIOASSAY | Hazardous Substances Data Bank 2004 |
| Bluegill | LC50 7.4 ppm/48 hr /Conditions of bioassay not specified | Hazardous Substances Data Bank 2004 |
| carp | highly toxic | Hazardous Substances Data Bank 2004 |
| crustaceans | LC50: slightly toxic | PAN 2004 |
| Daphnia magna population | A concentration of 0.2 ppm diuron was lethal | Hazardous Substances Data Bank 2004 |
| fish | LC50: slightly toxic | PAN 2004 |
| molluscs | LC50: moderately toxic | PAN 2004 |
| Oncorhynchus kisutch (fish) | LC50 16 mg/l/48 hr /Conditions of bioassay not specified | Hazardous Substances Data Bank 2004 |
| phytoplankton | LC50: very highly toxic | PAN 2004 |
| Rainbow trout | LC50 4.3 ppm/48 hr /Conditions of bioassay not specified | Hazardous Substances Data Bank 2004 |
| zooplankton | LC50: slightly toxic | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | expected to adsorb to suspended solids and sediment based upon the range of Koc values 224-879; Diuron is 67-99% degraded in 10 weeks under aerobic conditions by mixed cultures isolated from pond water and sediment. | Hazardous Substances Data Bank 2004 |
| Environmental Acceptibility | anaerobic half life of diuron: 14 days and CPD of 35 days | Thomas 2003 |
| Byproducts | major product was 3,4-dichloroaniline(12). 3-(3,4-Dichlorophenyl)-1-methylurea and 3-(3,4-dichlorophenyl)urea (CPDU) were also identified | Hazardous Substances Data Bank 2004 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | Avoid freezing liquid suspension. Dry formulations are stable under normal storage | Hazardous Substances Data Bank 2004 |
| Handling | Contact with diuron (particularly in concentrated form) may irritate the eyes, nose, throat, and skin. Exposure to diuron may even prove fatal if sufficient quantities are inhaled, swallowed, or absorbed through the skin | Hazardous Substances Data Bank 2004 |

## Laws and Regulations

## Citations



| | | |
|---|---|---|
| Hazardous Substances Data Bank, , . 2004. | Diuron | National Library of Medicine Toxnet System : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org / : - |
| Thomas, KV, M McHugh, M Hilton, M Waldock. 2003. | Increased persistence of antifouling paint biocides when associated with paint particles | Environmental Pollution 123: 153-161 |
| Thomas, KV, TW Fileman, JW Readman, MJ Waldock. 2001. | Antifouling Paint Booster Biocides in the UK Coastal Environment and Potential Risks of Biological Effect | Marine Pollution Bulletin 42: 677-688 |

# Dowicil 75

**$C_9H_{16}ClN_4 \bullet Cl$** **CAS_#** 4080-31-3

designed to provide reliable and effective antimicrobial protection in a wide range of water-based products and formulations

**Other Names** 1-(3-chloroallyl)-3,5,7-triaza-1-azonia; 3,5,7-triaza-1-azoniaadamantane, 1-(3-chloroallyl)-, chloride; 1 - (3 - Chloroallyl) - 3,5,7 - triaza - 1 - azoniaadamantane chlorid

**Trade_Names** Dowco 184, Dowicide Q, Dowicil 100, Dowicil 75; Quaternium 15

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | white to cream color powder | Hazardous Substances Data Bank 2004 |
| pH | hydrolysis rate increases with increasing pH | Hazardous Substances Data Bank 2004 |
| pH | acidic degrades rapidly; neutral to alkaline degrades slowly | U.S. EPA 1995 |
| Density | 0.4 g/cu cm | Hazardous Substances Data Bank 2004 |
| Solubility in water | 127.2 g/100 g water | Hazardous Substances Data Bank 2004 |
| Stability | rapid degradation; half life is 1.5 days and 95-100% degradation after 7 days | Hazardous Substances Data Bank 2004 |
| Stability | dissipates by abiotic hydrolysis; not persistant | U.S. EPA 1995 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| crustaceans | LC50: not acutely toxic | PAN 2004 |
| fish | LC50: slightly toxic | PAN 2004 |
| fish and aquatic invertebrates | slightly toxic. | U.S. EPA 1995 |
| molluscs | EC50: intoxication | PAN 2004 |
| zooplankton | EC50: intoxication, mortality, reproduction | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | expected to adsorb to suspended solids and sediment based on Koc of 600. Log Kow of -0.10. | Hazardous Substances Data Bank 2004 |
| Byproducts | decomposes to formaldehyde in aqueous solution | U.S. EPA 1995 |
| Effectiveness Factor | degrades rapidly under acidic conditions. Under neutral to alkaline conditions, it degrades more slowly. | U.S. EPA 1995 |

## Shipboard Use

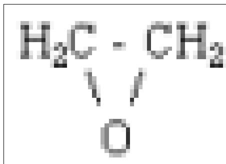
| | | |
|---|---|---|
| Storage | stable under ambient conditions | Hazardous Substances Data Bank 2004 |
| Handling | skin irritant use chemical resistant gloves at a minimum | Hazardous Substances Data Bank 2004 |
| Handling | causes moderat acute dermal toxicity so workers should wear gloves. | U.S. EPA 1995 |

## Laws and Regulations

## Citations


| | | |
|---|---|---|
| Hazardous Substances Data Bank, , . 2004. | N-(3-CHLOROALLYL)HEXAMINIUM CHLORIDE | National Library of Medicine Toxnet System : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org / : - |
| U.S. EPA, , . 1995. | R.E. D FACTS Dowicil CTAC | EPA-738-F-95-016 : 1-5 |

# Ethylene Oxide



$C_2H_4O$ **CAS_#** 75-21-8

Available as colorless, liquified gas and used as a sterilant and fumigant.

**Other Names** Dihydrooxirene; dimthylene oxide; Epoxyethane; 1,2-Epoxyethane; Oxacyclopropane; Oxidoethane

**Trade_Names** Ethene oxide; ETO; Oxirene; T-Gas; Oxiran; Oxyfume; Oxirane

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | colorless gas or liquid | Dow Chemical Company 1999 |
| Physical State | colorless gas | Hazardous Substances Data Bank 2004 |
| pH | acidic conditions have positive effect on hydrolysis rate. | Dow Chemical Company 1999 |
| Density | 0.882 at 10 deg C | Hazardous Substances Data Bank 2004 |
| Specific gravity | 0.875 | Dow Chemical Company 1999 |
| Solubility in water | miscible | Dow Chemical Company 1999 |
| Solubility in water | miscible in all proportions with water | Hazardous Substances Data Bank 2004 |
| Stability | not persistent in the environment degrades by biochemical oxidation, reactivity, volatilization, and dilution. Does not readily adsorb onto sediments. Half life of 9 days in 3% salt water | Dow Chemical Company 1999 |
| Stability | half-life if 1 hour to 3.8 days depending on water body. Degrade due to hydrolysis. | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| brine shrimp | 24-h LC50 = 350, 570, >500 mg/L; 48-h LC50 = 490, >500, 1000 mg/L (static, salt water) | Dow Chemical Company 1999 |
| Daphnia magna | 24-h LC50 = 260, 270,>300 mg/L; 48-h LC50 = 137, 200, 300 mg/L (static, fresh water) | Dow Chemical Company 1999 |
| fathead minnow | maximum safe concentration = 41 mg/L; 96-h LC 50 = 86, 90, 274 mg/L; 48-h LC50 = 89 mg/L; 96-h LC50 = 84 mg/L (static and fresh water) | Dow Chemical Company 1999 |
| goldfish | 24-h LC50 = 90 mg/L (static, freshwater) | Dow Chemical Company 1999 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | Ethylene glycol degraded rapidly. | Dow Chemical Compan 1999 |
| Environmental Acceptibility | primarily lost by volatilization, hydrolysis, and biodegradation. Not tend to adsorb to sediments - low Kow (log Kow of -0.3), Koc of 16 | Hazardous Substances Data Bank 2004 |
| Byproducts | ethylene glycol due to hydrolysis | Dow Chemical Compan 1999 |
| Byproducts | ethylene glycol and ethylene chlorohydrin | Hazardous Substances Data Bank 2004 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | Depends on formulation. | DOT 2002 |
| Storage | Store at ambient conditions. fire or explosion, may be ignited by heat, sparks, flame. Stable in water. | Hazardous Substances Data Bank 2004 |
| Handling | irritating to eyes, respiratory tract, and skin. Wear chemical protective clothing, goggles, wear SCBA | Hazardous Substances Data Bank 2004 |

### Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |

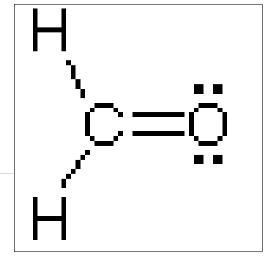
### Citations



| | | |
|---|---|---|
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| Dow Chemical Company, , Shell Chemical Co., Equistar Chemicals, Sunoco. 1999. | Ethylen Oxide Users Guide | Second Edition : - |
| Hazardous Substances Data Bank, , . 2004. | Ethylene Oxide | National Library of Medicine Toxnet System : - |

# Formaldehyde

$CH_2O$ **CAS_#** 50-00-0




Formaldehyde is a colorless gas with a strong odor which is usually mixed in a water and Methanol solution. It is used as a bactericide, fungicide, an intermediate in chemical and resin manufacturing, in pressed-wood products, and in textile finishing. Also available as a colorless liquid.

**Other Names** Methanal; Methylene oxide; Formalin

**Trade_Names**

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | colorless liquid | Hazardous Substances Data Bank 2004 |
| pH | 2.8 - 4.0 | Hazardous Substances Data Bank 2004 |
| pH | Ineffective throughout pH range on bacterial spores at 8% concentration | Sagripanti 1996 |
| Density | 1.067 | Hazardous Substances Data Bank 2004 |
| Specific gravity | 0.816 | Hazardous Substances Data Bank 2004 |
| Solubility in water | 400000 mg/L at 20 deg C | Hazardous Substances Data Bank 2004 |
| Stability | degradation complete in 48 hours under anaerobic conditions | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| Bacillus subtillus spores | 8% resulted in < 90% inactivation (ineffective) | Sagripanti 1996 |
| Bacillus subtillus spores | 8% for 30 min at 20 deg C is ineffective (< 90% inactivation) | Bacillus subtillus spores 1996 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | Koc of 37, not expected to adsorb to suspended solids and sediments. Log Kow = 0.35 | Hazardous Substances Data Bank 2004 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | Material may be stowed on deck or under deck on a cargo vessel and on a passenger vessel. If 25% or more formaldehyde in solution, material should be stowed clear of living quarters. | DOT 2002 |
| Storage | Protect against physical damage. Separate from oxidizing and alkaline material. Flammable. | Hazardous Substances Data Bank 2004 |
| Handling | contact with skin causes irritation, tanning effect, and allergic sensitization. Formaldehyde vapor is very irritating to mucous membranes and toxic to man. | Hazardous Substances Data Bank 2004 |
| Corrosivity | Corrosive hazard class when solution is not less than 25% formaldehyde. All solutions should be labeled as corrosive and flammable. | DOT 2002 |
| Corrosivity | aqueous formaldehyde is corrosive to carbon steel, but vapor phase is not. | Hazardous Substances Data Bank 2004 |
| Ventilation | Corrosive and flammable. | DOT 2002 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Canada | Canada Shipping Act - Part (XV): Pollutant Substances Regulations (CRC, c. 1458) | http://www.tc.gc.ca/acts-regulations/GENERAL/C/csa/regulations/050/csa052/csa52.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East Asian nations | East Asian Seas Action Plan | |

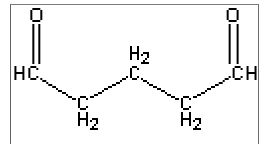
| | | |
|---|---|---|
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| European Union | Existing Substances Regulation 793/93/EEC | http://ecb.jrc.it/Legislation/1993R0793EC.pdf |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |
| USA | Occupational Safety and Health Act | http://www4.law.cornell.edu/uscode/29/ch15.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations


| | | |
|---|---|---|
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| Hazardous Substances Data Bank, , . 2004. | Formaldehyde | National Library of Medicine Toxnet System : - |
| Sagripanti, J, A Bonifacino. 1996. | Comparative Sporicidal Effects of Liquid Chemical Agents | Applied Environmental Microbiology 62: 545-551 |

# Glutaraldehyde

$C_5H_8O_2$ **CAS_#** 111-30-8



A strong sporicide, generally unaffected by organic material, non-corrosive. Used in hospitals and laboratories as a disinfectant and in tanning as a biological fixative. Available as a colorless liquid.

**Other Names** 1,5-Pentanedial; Glutaral; Glutardialdehyde; Glutaric dialdehyde; Aqucar 545

**Trade_Names** Cidex; Cidex Long-life; Microcide; Nalco 7338; Neoquat LA; Safeguard; Sepacid GA 50; Sonacide; Ucarcide 125; Ucarcide 225; Ucarcide 250; Uconex 350

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| pH | Rate of reaction is pH dependent, increasing over range of 4-9 | Hopwood 1970 |
| pH | Mildly acidic. Usually supplied in range of 3-6. | Lubomudrov 1997 |
| pH | More effective at higher pH | Oemcke 1999 |
| Density | 1.13 (50%), 0.72 (100%) | Lubomudrov 1997 |
| Specific gravity | 1.129 | Lubomudrov 1997 |
| Solubility in water | 100% | Lubomudrov 1997 |
| Stability | Affected by pH | Lubomudrov 1997 |
| Inactivation | Only aldehyde to exhibit excellent sporicidal activity. | Scott 1991 |
| Inactivation | 0.02% solution is rapidly effective against gram-positive and gram-negative species; 2 % solution is capable of killing vegetative species including S. aureus, P. vulgaris, E. coli, and P. aeruginosa within 2 minutes. | Stonehill 1963 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| Algae | Dose depends on target organism and volume of ballast water. | Lubomudrov 1997 |
| Bacillus anthracis | 4-log inactivation in 15-30 minutes using ???? Concentration | Rubbo 1967 |
| Bacillus spp | 2% solution inactivated spores in 3 hours | Stonehill 1963 |
| Bacillus subtillus spores | 30 min*mg/L | Sagripanti 1996 |
| Bacteria | Dose depends on target organism and volume of ballast water. | Lubomudrov 1997 |
| Bacterial spores | 20,000 mg/L | Oemcke 1999 |
| Bacterial spores | 20,000 mg/L | Oemcke 1999 |
| Clostridium spp | 2% solution inactivated spores in 3 hours | Stonehill 1963 |
| Clostridium tetani | 4-log inactivation in 15-30 minutes using ???? Concentration | Rubbo 1967 |
| Daphnia magna | 50% solution for 48 hours LC50 = 11.5 ppm, LC100 = 23 ppm. | Lubomudrov 1997 |
| E. Coli | 100 ug/mL alkaline glutaraldehyde completely inactivates 2x10^8 cells/mL in 10 minutes compared to 45% inactivation with solution | McGucken 1973 |
| Feline Calicivirus (FCV) | Final concentration of 0-5 % Glutaraldehyde give a Log10 reduction of 5 | Doultree 1999 |
| fish | LC50: slightly toxic | PAN 2004 |
| Fungi | Sonacide (an acid-based glutaraldehyde formulation) was effective against A. niger and A. fumigatus. Sporicidin (a glutaraldehyde-phenate mixture) was NOT effective even after 90 minutes. 0.5% alkaline glutaraldehyde inhibits mycelial growth and sporulation and spore swelling is entirely halted. | Scott 1991 |
| fungi | EC50: population | PAN 2004 |
| Grass shrimp | 100% solution for 96 hours LC50 = 41 ppm, LC100 = 82 ppm. | Lubomudrov 1997 |
| molluscs | EC50: intoxication | PAN 2004 |
| Poliovirus | 500 mg/L | Oemcke 1999 |
| Rainbow trout | 50% solution for 96 hours LC50= 23.7 ppm, LC100 = 47.4 ppm. | Lubomudrov 1997 |
| Viruses | 500 mg/L for poliovirus | Oemcke 1999 |
| Viruses | Dose depends on target organism and volume of ballast water. | Lubomudrov 1997 |
| zooplankton | LC50: slightly toxic | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | concentration released into environment depends on initial concentration. Levels <5ppm are considered to be nonbiocidal. Concentrations <1ppm are classified as "readily" biodegradable. Once released into the environment, it will remain in aqueous solution. Under aerobic conditions, glutaraldehyde decomposes to carbon dioxide. Under anaerobic conditions, glutaraldehyde decomposes to 5-hydroxypentanal which is further metabolized to 1,5-pentanediol. | Lubomudrov 1997 |
| Byproducts | Reaction products with amino acids | Kirkeby 1987 |
| Byproducts | Reacts with protein to form unsaturated polymer | Monsan 1975 |
| Inhibitors | Generally unaffected by organic material. Low pH reduces effectiveness. Efficacy improves as temberpature increases. | Oemcke 1999 |
| Effectiveness Factor | Mixing into ballast tank residuals likely to be difficult. 20,000 mg/L doses will be expensive. | Oemcke 1999 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | Store in cool area (<room temperature, ideally 25-37 degrees C). Storage at elevated temperatures may shorten shelf-life. | Lubomudrov 1997 |
| Size | Small pumps that meter the chemical into ballast water. Systems could be installed into existing vessels in addition to being integrated into new vessel design. | Lubomudrov 1997 |
| Corrosivity | Will not permanently damage ballast piping or tank systems, nor adversely affect protective coatings on pipes when in solution. | Lubomudrov 1997 |
| Corrosivity | Non-corrosive | Oemcke 1999 |
| Limits | Mixing chemical in tank difficult and doses of 20,000 mg/L are expensive. | Oemcke 1999 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East Asian nations | East Asian Seas Action Plan | |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |

| | | |
|---|---|---|
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Occupational Safety and Health Act | http://www4.law.cornell.edu/uscode/29/ch15.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

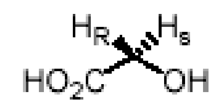
## Citations


| | | |
|---|---|---|
| Doultree, JC, Druce, J. D., Birch, C. J., Bowsden, D. S., and J. A. Marshall. 1999. | Inactivation of feline calicivirus, a Norwalk virus surrogate | The Hospital Inspection Society : - |
| Hopwood, D, Allen, C.R., and C. McCabe. 1970. | The reaction between glutaraldehyde and various proteins: an investigation of their kinetics | Histochem J 2: 137-150 |
| Kirkeby, S, Jacobsen, P., and D. Moe. 1987. | Glutaraldehyde pure and impure. A spectroscopic investigation of two commercial glutaraldehyde solutions and | Anal. Lett 20: 303-315 |
| Lubomudrov, L, R Moll, M Parsons. 1997. | An Evaluation of the Feasibility and Efficacy of Biocide Application in Controlling the Release of Nonindigenous Aquatic Species from Ballast Water | Report to MI DEQ, Office of the Great Lakes : - |
| McGucken, PA, W. Woodside. 1973. | Studies on the mode of action of glutaraldehyde on Escherichia Coli | J. Appl. Bacteriol 36: 419- |
| Monsan, P, Puzo, G., and H. Mazarguil. 1975. | Ētude du mechanisme d' establissement des liaisons glutar-aldēhyde-protéines | Biochimica 57: 1281- |
| Oemcke, D, . 1999. | The Treatment of Ships' Ballast Water | EcoPorts Monograph Series 18: - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Rubbo, SD, Gardner, J.F., and R.L. Webb. 1967. | Biocidal activities of glutaraldehyde and related compounds | . Appl. Bacteriol 30: 78- |
| Sagripanti, J, A Bonifacino. 1996. | Comparative Sporicidal Effects of Liquid Chemical Agents | Applied Environmental Microbiology 62: 545-551 |
| Scott, E, S Gorman. 1991. | Glutaraldehyde. In: Disinfection, Sterilization, and Preservation | S.S. Block (Ed) Lea & Feviger, Philadelphia : - |
| Stonehill, AA, Krop, S., and P.M. Borick. 1963. | Buffered glutaraldehyde, a new chemical sterilizing solution | Am. J. Hosp. Pharm 20: 458- |

# Glycolic Acid

$C_2H_4O_3$ **CAS_#** 79-14-1

Moist white crystalline powder



**Other Names** Acetic acid; hydroxy-;

**Trade_Names**

**Environmental Acceptability**

**Shipboard Use**

**Laws and Regulations**

| Country_Region | Regulation | Web site |
|---|---|---|
| | East Asian Seas Action Plan | |
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |

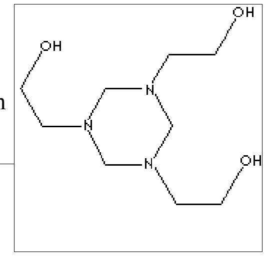
| | | |
|---|---|---|
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean Region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations


| | | |
|---|---|---|
| Oemcke, D, . 1999. | The Treatment of Ships' Ballast Water | EcoPorts Monograph Series 18: - |

# Grotan

$C_9H_{21}N_3O_3$ **CAS_#** 4719-04-4



Alkaline, clear to light yellow viscous liquid used in formulating bactericide and fungicide. It is used as a preservative in oil field applications

**Other Names** hexahydro-1,2,5-tris(2-hydroxyethyl)-s-triazine; Hexahydro- 1,3 ,5-tris(2-hydroxyethyl)-s-triazine; 1,3,5-triazine-1,3,5-(2H, 4H, 6H)-triethanol; Triazinetriethanol; Tris(2-hydroxyethyl)hexahydro-s-triazine;

**Trade_Names** Grotan; Triadine 3; Onyxide 200 MUP

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | clear viscous liquid | GR OShea Company 2004 |
| pH | 10.3 - 11.3 at 25 deg C | GR OShea Company 2004 |
| Specific gravity | 1.152 | GR OShea Company 2004 |
| Viscosity | 250 cps | GR OShea Company 2004 |
| Solubility in water | miscible with water in all proportions | GR OShea Company 2004 |
| Stability | normal shelf life is a minimum of 2 years | GR OShea Company 2004 |

## Environmental Acceptability

## Shipboard Use

| | | |
|---|---|---|
| Storage | Store in original container for ~2 years when stored between -10 deg C and 40 deg C | GR OShea Company 2004 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |

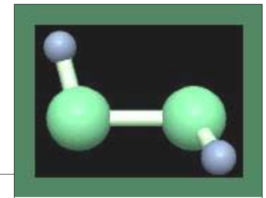
## Citations



| | | |
|---|---|---|
| GR OShea Company, , . 2004. | Grotan | http://www.groshea.com/troy/grotan.html : - |

# Hydrogen Peroxide

$H_2O_2$ **CAS_#** 7722-84-1



Hydrogen peroxide solutions of 10-25% are used to purify drinking water; treat contaminated water supplies; sterilize spacecraft and disinfect contact lenses. Hydrogen peroxide solutions of 15-35% are used to sterilize the contact surfaces of food packaging. Available as a colorless, syrupy liquid or as a crystalline solid (below 12 deg. F).

**Other Names** dioxogen; Dihydrogen dioxide; Genoxide+so; Hioxyl; Hydrogen dioxide; hydroperoxide; hydrozone; Lensan A; Mirasept; Oxysept; Oxzone; Pegasyl; Percarbamid; Perhydrol; Peroxal; Peroxol; Peroxyl; Proxy; Truzone

**Trade_Names** Albone; Kastone; Perone; Tysu; Interox

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | colorless liquid | Hazardous Substances Data Bank 2004 |
| pH | Ineffective throughout pH range | Sagripanti 1996 |
| Density | 1.4425 at 25 deg C | Hazardous Substances Data Bank 2004 |
| Solubility in water | miscible with water; In water 1000000 mg/L at 25 deg C. | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| Bacillus subtillus spores | 10% is ineffective (<90% inactivation) at room temperature for 30 min | Sagripanti 1996 |
| Crustaceans | from EC50: behaviro, biochemistry, development, intoxication, mortality | PAN 2004 |
| Daphnia magna | Minimum concentration of 18,000 ppm, maximum concentration of 32,000 ppm, and a mean concentraiton of 24,000 ppm will result in the immobility of the species less than 24 hours. | PAN 2004 |
| Daphnia magna | Minimum concentration of 18,000 ppm, maximum concentration of 32,000 ppm, and a mean concentraiton of 24,000 ppm will result in the immobility of the species less than 24 hours. | Pesticide Ecotoxicity Database 2000 |
| Dreissena polymorpha | minimum concentration of 29,300 ug/L, maximum concentration of 298,000 ug/L and a mean concentration of 29,600 ug/L will result in mortality in 3.5 hours. | Matisoff 1996 |
| Fish | EC50: behavior, biochem, feeding behavior, growth, mortality | PAN 2004 |
| Fish | LC50: not acutely toxic | PAN 2004 |
| Fungi | EC50: population | PAN 2004 |
| Molluscs | behavior, mortality, reproduction | PAN 2004 |
| Oscillatoria rubescens | 1,750 ug/L will cause mortality in less than 1 day | Barroin 1986 |
| Phytoplankton | EC50: biochem, histology, mortality, physiology, population | PAN 2004 |
| Saprolegnia sp. | 100,000 ug/L is toxic to the population | Marking 1994 |
| Zooplankton | EC50: behavior, intoxication, mortality | PAN 2004 |

**Environmental Acceptability**

**Shipboard Use**

| | | |
|---|---|---|
| Application | Product: $0.34 per lb-50% (FOB Houston, TX); Freight: $3.50 per mile (regardless of delivery volume) | U.S. Peroxide 2004 |
| Storage | Must be stowed "on deck only" on a cargo vessel and on a passenger vessel carrying a number of passengers limited to not more than the larger of 25 passengers or one passenger per each 3 m of overall vessel length, but the material is prohibited on passenger vessels in which the limiting number of passengers is exceeded. Shade material from radiant heat. Stow separated from flammable solids, permanganates, and powdered metal. | DOT 2002 |
| Storage | Storage tanks should be constructed of high-purity aluminium; keep away from direct heat and sun and combustible materials. Do not touch damaged containers or spilled material unless wearing appropriate protective clothing. | Hazardous Substances Data Bank 2004 |
| Handling | Oxidizer hazard class | DOT 2002 |
| Handling | Inhalation, ingestion, or contact (skin, eye) with vapors or substance may cause severe injury, burns, or death; protective chlothing: Wear positive pressure self-contained breathing apparatus (SCBA) | Hazardous Substances Data Bank 2004 |
| Corrosivity | hydrogen peroxide destroys residual chlorine and reduced sulfur compounds thiosulfates, sulfites, and sulfides which form corrosive acids whtn condensed onto processing equipment and oxidized | U.S. Peroxide 2004 |

| | | |
|---|---|---|
| Ventilation | by air<br>proper ventilation required | Hazardous Substances Data Bank 2004 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East Asian nations | East Asian Seas Action Plan | |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| European Union | Existing Substances Regulation 793/93/EEC | http://ecb.jrc.it/Legislation/1993R0793EC.pdf |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | CERCLA section 103, codified at 40 CFR part 302, in addition to requirements of 40 CFR part 355 | |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |
| USA | Occupational Safety and Health Act | http://www4.law.cornell.edu/uscode/29/ch15.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |

| | | |
|---|---|---|
| Wider Caribbean region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations

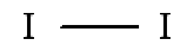


| | | |
|---|---|---|
| Barroin, , Feuillade. 1986. | Hydrogen Peroxide as a Potential Algicide for Oscillatoria rubescens | Water Research 20: 619-623 |
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| Hazardous Substances Data Bank, , . 2004. | Hydrogen peroxide | National Library of Medicine Toxnet System : - |
| Marking, LL, JJ Rach and TM Schreier. 1994. | Evaluation of Antifungal Agents for Fish Culture | Prog Fish Cult 56: 225-231 |
| Matisoff, G, G Brooks and BI Bourland. 1996. | Toxicity of Chlorine Dioxide to Adult Zebra Mussels | J Am Water Works Assoc 88: 93-106 |
| Oemcke, D, . 1999. | The Treatment of Ships' Ballast Water | EcoPorts Monograph Series 18: - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Sagripanti, J, A Bonifacino. 1996. | Comparative Sporicidal Effects of Liquid Chemical Agents | Applied Environmental Microbiology 62: 545-551 |
| U.S. Peroxide, , . 2004. | Intro to H2O2 | www.h2o2.com : - |

# Iodine

$I_2$ **CAS_#** 7553-56-2

Iodine is a bluish-black, lustrous solid used as a microbiocide, fungicide, or herbicide.



**Other Names** iodine crystals; molecular iodine

**Trade_Names**

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Solubility in water | only slightly souble in water; Solubility in water is increased by alkali bromides and decreased by sulfates and nitrates. Measurements: 0.034 g/kg in water @ 25 deg C; 0.029 g/100 cc in water @ 20 deg C; 0.078 g/100 cc in water @ 50 deg C; 330 mg/l in water at 25 deg C | Hazardous Substances Data Bank 2004 |
| Inactivation | Iodine causes chemical action and cell/protein disruption | Letcher 2003 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| Feline Calicivirus (FCV) | Final concentration of 0-8% give a Log10 reduction of 1-25 | Doultree 1999 |
| fish | moderately toxic | PAN 2004 |
| fungi | no LC50 but population effects from EC50 | PAN 2004 |
| Waterborne microorganisms | Iodinated resins: most waterborne microorganisms susceptible to doses up to 5 mg/L as I2 | Letcher 2003 |
| zooplankton | highly toxic | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | Iodine at certain concentrations is toxic to certain fresh water and marine species. Acceptable levels for specific applications are not known. | Letcher 2003 |
| Byproducts | Iodine: same as for bromine except resulting iodinated organics are typically much lower in concentration; reduced form of free iodine-- iodide ion, I- | Letcher 2003 |

## Shipboard Use

| | | |
|---|---|---|
| Handling | Iodine vapor is irritating to the eyes | Hazardous Substances Data Bank 2004 |
| Corrosivity | Iodine is a powerful oxidizing agent | Hazardous Substances Data Bank 2004 |
| Power Requirements | Needs research | Letcher 2003 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| | East Asian Seas Action Plan | |
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
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| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |

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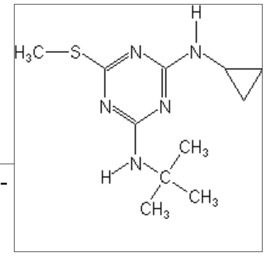
|---|---|---|
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean Region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

**Citations**


| | | |
|---|---|---|
| Brion, GM, J. Silverstein. 1999. | Iodine disinfection of a model Bacteriophage, MS2, demonstrating apparent rebound | Water Research 33: 169-179 |
| Doultree, JC, Druce, J. D., Birch, C. J., Bowsden, D. S., and J. A. Marshall. 1999. | Inactivation of feline calicivirus, a Norwalk virus surrogate | The Hospital Inspection Society : - |
| Hazardous Substances Data Bank, , . 2004. | Iodine | National Library of Medicine Toxnet System : - |
| Letcher, J, . 2003. | Telephone conversation with Jerry Letcher, Sales Manager | Pentair Water Treatment/Plymouth Products : - |
| Oemcke, D, . 1999. | The Treatment of Ships' Ballast Water | EcoPorts Monograph Series 18: - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |

# Irgarol 1051 (Cybutryne)

$C_{11}H_{19}N_5S$ **CAS_#** 28159-98-0



Microbiocide used for antifouling. Available as a white or slightly yellow powder.

**Other Names** 1,3,5-Triazine-2,4-diamine; N-cyclopropyl-N'-(1,1-dimethylethyl)-6-(methylthio)-; 2-(tert-Butylamino)-4-(cyclopropylamino)-6-(methylthio)-1,3,5-triazine; 2-(tert-butylamino)-4-cyclopropylamino-6-methylthio-1,3,5-triazine; Cyclopropyl-n'(1,1,dimethylethyl)-6-(methylthio)1,3,5-triazine,2,4,di=; N-Cyclopropyl-N'-(1,1-dimethylethyl)-6-(methylthio)-1,3,5-triazine-2,4-diamine; s-Triazine; 2-(tert-butylamino)-4-(cyclopropylamino)-6-(methylthio)-

**Trade_Names** Irgarol 1051; Irgarol 1071

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | crystalline powder | Ciba Specialty Chemicals, Inc. 1999 |
| Solubility in water | 7 mg/L; Kow = 3.95; Koc = 3100 L/kg (dissolved phase), 1240 L/kg (suspended phase) | Albanis 2002 |
| Solubility in water | Water solubility dependent on salinity values at 25 deg C and pH of 7: 0.0 Mol NaCl/L = 9mg/L; 0.3 Mon NaCl/L = 5.9 mg/L; 0.6 Mol NaCl/L = 1.8 mg/L | Ciba Specialty Chemicals, Inc. 1999 |
| Inactivation | blocks pivotal step of electron transport | Ciba Specialty Chemicals, Inc. 1999 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| Algae | Concentration between <1 and 1700 ng/l. Safety level of 0.4 ug/L for algae, 1.6 ug/L for other aquatic organsims. | Thomas 2001 |
| Anthocidaris crassispina | At higher concentration of 10 mg/L, the eggs were mostly unfertilized and later showed induced cytolysis. Retarded cleavage and development were evident at 1 mg/L. The concentration of 0.01-0.1 mg/L induced cytolysis and allowed a normal state. | Kobayashi 2002 |
| aquatic plants | EC50: accumulation, growth, physiology, population | PAN 2004 |
| Crustacean, A. salina | For a concentration level of 40 mg/L, Irgarol caused 30% mortality of the organisms | Okamura 2000 |
| cyanobacteria (Anabaena flos-aquae) | 2 ug/L | Ciba Specialty Chemicals, Inc. 1999 |
| D. magna | The toxicity of Irgarol 1051 was by a 48 h-EC50 value of 8.1 mg/L and a LC50 value of 0.86 mg/L. | Okamura 2000 |
| Daphnia | LC0 is 440 ug/L | Ciba Specialty Chemicals, Inc. 1999 |
| diatoms | 0.1 to 0.4 ug/L | Ciba Specialty Chemicals, Inc. 1999 |
| Enteromorpha intestinalis | An EC50 value of 5.4 ug/L inhibted the growth. | Okamura 2000 |
| fish | LC50: moderately toxic | PAN 2004 |
| green algae (Raphidocelis subcapitata) | 1 ug/L | Ciba Specialty Chemicals, Inc. 1999 |
| Hemicentrotus pulcherrimus | At higher concentration of 10 mg/L, the eggs were mostly unfertilized and later showed induced cytolysis. Retarded cleavage and development were evident at 1 mg/L. The concentration of 0.01-0.1 mg/L induced cytolysis and allowed a normal state. | Kobayashi 2002 |
| higher plants (Lemna gibba) | 2 ug/L | Ciba Specialty Chemicals, Inc. 1999 |
| Lemma gibba | A 14-day EC50 value of 1.62 ug/L inhibited the growth. | Okamura 2000 |
| molluscs | EC50: intoxication | PAN 2004 |
| Mysid shrimps | LC0 is 130 ug/L | Ciba Specialty Chemicals, Inc. 1999 |
| oyster larvae | LC50 over 48 hours was 3200 ug/L. | Ciba Specialty Chemicals, Inc. 1999 |
| Periphyton community | At concentration levels of 63-250 ng/L in seawater, Irgarol was shown to be capable of damaging sensitive periphyton communities. | Okamura 2000 |
| Periphyton community | Detection limit of 1-5 ng/L. Irgarol is toxic to microalgal communities of Enteromorpha intestinalis at 50 ng/L and long term effects on periphyton communities in coastal water were observable at ambient levels between 63 and 250 ng/L | Liu 1998 |
| Periphyton community | Irgarol with concentration of 1 nM (approximately 250 ng/L) produced changes in the structure of the periphyton community. | Connelly 2001 |

| | | |
|---|---|---|
| phytoplankton | EC50: ecosystem process, physiology, population | PAN 2004 |
| Rainbow Trout | The toxicity of Irgarol 1051 was by a 48 h-EC50 value of 8.1 mg/L and a LC50 value of 0.86 mg/L. | Okamura 2000 |
| S. capricornutum | The phototoxicity of Irgarol has been reported as 1.26 ug/L (120 h-EC50) and 0.45 ug/L (120 h-EC50). | Okamura 2000 |
| Sea organism | Cell density range from 0.136 ppb for Navicula pelliculosa (a freshwater diatom) to 2.07 for Anabaena flos-aquae (a freshwater blue algae). The value varies from 400 ppb for Misidopis bahia to 5300 ppb for Daphnia magna. | Voulvoulis 2000 |
| Skeletonema costatum | The phototoxicity of Irgarol has been reported as 1.26 ug/L (120 h-EC50) and 0.45 ug/L (120 h-EC50). | Okamura 2000 |
| V. fisheri | For a concentration level up to 50 mg/L, had little effect on the organism. | Okamura 2000 |
| zooplankton | LC50: moderately toxic | PAN 2004 |
| Zostera marina | An Irgarol concentration of 0.18 ug/L can reduce the growth rate of the leaves. Where the concentration was found mainly in leaves than in roots. | Scarlett 1999 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | half life of 25 days; does not bioaccumulate and is of low risk to animals like oysters, curstaceans, fish or birds at concentrations designed to inhibit target organisms (e.g., photosynthetic organisms). Koc: 3100 L/kg (dissolved phase, 1240 L/kg (suspended phase). | Ciba Specialty Chemicals, Inc. 1999 |
| Environmental Acceptibility | not readily degraded with half life of 100 days | Thomas 2000 |
| Environmental Acceptibility | anaerobic half lifeover 226 days | Thomas 2003 |
| Byproducts | inactive metabolites | Ciba Specialty Chemicals, Inc. 1999 |
| Byproducts | Chemical degradation of 1051 by mercuric chloride appeared to follow the reaction of a catalyzed hydrolysis and the mech apparently involved the formation of bidentate chelation, which weakened the cyclopropylamino bond and resulted in formation of a hydrolysis product M1. M1 is the major degradation product during the biological and chemical degradation of 1051. | Liu 1998 |
| Byproducts | iodegradation, photodegradation, and chemical hydrolysis of Irgarol 1051 as the result in n-dealkylation to yield 2-methylthio-4-tert-butylamino-6-amino-s-triazine (GS26575) as the principle of degradation product | Thomas 2000 |
| Inhibitors | Half life: 100 or 200 days for marine or freshwater, respectively | Albanis 2002 |
| Effectiveness Factor | As a herbicide, Irgarol 1051 is much more toxic to algae and higher plant species, mainly due to inhibition of photosynthesis. | Okamura 2000 |
| Effectiveness Factor | When some flushing is allowed (in open tidal marinas, the runoff is quickly diluted and flushed out by the tide), 1051 concentration was found higher than non-flushing | Thomas 2001 |

## Shipboard Use

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| | East Asian Seas Action Plan | |
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |

| | | |
|---|---|---|
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean Region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations


| | | |
|---|---|---|
| Albanis, TA, DA Lambropoulou, VA Sakkas, IK Konstantinou. 2002. | Antifouling Paint Booster Biocide Contamination in Greek Marine Sediments | Chemosphere 48: 475-485 |
| Ciba Specialty Chemicals, Inc., , . 1999. | Part 1 General Information: Physical Information and algaecide properties, health and environmental effects, risk assessemnt and registration status | : 1-9 |
| Connelly, DP, JW Readman, AH Knap, J Davies. 2001. | Contamination of the coastal waters of Bermuda by organotins and the triazine herbicide Irgarol 1051 | Marine Pollution Bulletin 42: 409-414 |
| Kobayashi, N, H Okamura. 2002. | Effects of new antifouling compounds on the development of sea urchin | Marine Pollution Bulletin 44: 748-751 |
| Liu, D, G Pacepavicius, RJ Maguire, YL Lau, H Okamura, I Aoyama. 1998. | Survey for the occurrence of the new antifouling compound Irgarol 1051 in the aquatic environment | Water Research 33: 2833-2843 |
| Okamura, H, I Aoyama, D Liu, RJ Maguire, GJ Pacepavicius, YL Lau. 2000. | Fate and ecotoxicity of the new antifouling compound Irgarol 1051 in the aquatic environment | Water Research 34: 3523-3530 |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Scarlett, A, P Donkin, TW Fileman, SV Evans, ME Donkin. 1999. | Risk posed by antifouling agent Irgarol 1051 to the seagrass, Zostera marina | Aquatic Toxicology 45: 159-170 |
| Thomas, KV, M McHugh, M Hilton, M Waldock. 2003. | Increased persistence of antifouling paint biocides when associated with paint particles | Environmental Pollution 123: 153-161 |
| Thomas, KV, SJ Blake, MJ Waldock. 2000. | Antifouling Paint Booster Biocide Contamination in UK Marine Sediment | Marine Pollution Bulletin 40: 739-745 |
| Thomas, KV, TW Fileman, SV Evans, ME Donkin. 2001. | Antifouling paint booster biocides in the UK coastal environment and potential risks of biological effects | Marine Pollution Bulletin 42: 677-688 |
| Tolosa, I, Readman, J. W., Blaevoet, A.  Ghilini, S., Bartocci, J., and Horvat, M. 1996. | Contamination of Mediterranean (Cote d' Azur) Coastal Waters by Organotins and Irgarol 1051 Used in Antifouling Paints | Marine Pollution Bulletin PII: S0024-326X(96)00013-6. : - |

| | | |
|---|---|---|
| Voulvoulis, N, MD Scrimshaw, JN Lester. 2000. | Occurrence of four biocides utilized in antifouling paints as alternatives to organotin compounds in waters sediments of commercial estuary in the UK | Marine Pollution Bulletin 40: 938-946 |

# Mexel 432 (Fatty Amines)

**CAS_#** 00-00-0

This mixture of aliphatic amine surfactants is an anti-fouling material that acts as a corrosion inhibitor and scale dispersant as well as having activity against freshwater and saltwater mussels and barnacles; commercial mulluscicide using 1.7 % solution of (alkylamino)-3-aminopropane. Available as a slightly milky homogeneous liquid.

**Other Names** chemical name = (Alkylamino)-3-aminopropane

**Trade_Names** Mexel 432/0

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| pH | 11 | RTK Technologies, Inc 2004 |
| Stability | Half life of 22 hours in river water; decreases to ~ 6 hours with aeration and agitation | RTK Technologies, Inc 2004 |
| Inactivation | registered as a FIFRA muluscicide; effectvie in inhibiting toxic algae blooms and growth of bacteria colonies by retarding population growth by eliminating the habitat toxic to fish | RTK Technologies, Inc 2004 |

**Environmental Acceptability**

| | | |
|---|---|---|
| Environmental Acceptibility | contains no halogens, aromatics, quaternary amines, phosphorus, heavy metals, sulfur, cyclic hydrocarbons, zinc, or oxidizing agents | RTK Technologies, Inc 2004 |
| Byproducts | only products of its biodegradation are carbon dioxide, water, and a trace of nitrogen | RTK Technologies, Inc 2004 |

**Shipboard Use**

| | | |
|---|---|---|
| Application | 0.033 lbs/day per 100 sq ft of surface per day (for controlling mollusks in closed delivery systems) | RTK Technologies, Inc 2004 |
| Storage | Store the barrels hermetically closed far of bad weather and without intense heat source (<60 deg C). Avoid oxidizing agents (peroxides, perchlorates, nitrates, etc.) strong acid and halogen-organic compounds. | RTK Technologies, Inc 2004 |
| Handling | non-flammable, low vapor pressure -- safe to use in confined spaces | RTK Technologies, Inc 2004 |
| Corrosivity | Used as a corrosion inhibitor | RTK Technologies, Inc 2004 |
| Ventilation | well ventilated area | RTK Technologies, Inc 2004 |

**Laws and Regulations**

| Country_Region | Regulation | Web site |
|---|---|---|
| | East Asian Seas Action Plan | |
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or | http://www.unepmap.gr/pdf/dumping.pdf |

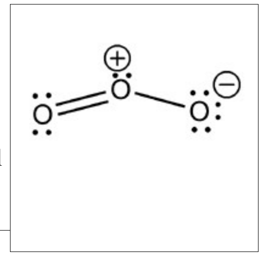
| | | |
|---|---|---|
| | Incineration at Sea | |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean Region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations


| | | |
|---|---|---|
| Arehmouch, L, V Tfibel, C Chaillou, F Ghillebaert, P Roubaud. 1998. | Lethal Effects of Mexel 432 to Common Carp Embryolarval Stages in River Water: Influence of Physiochemical Parameters in Synthetic ISO Water | Environmental Toxicology and Chemistry 17: 1767-1776 |
| RTK Technologies, Inc, , . 2004. | About Mexel® 432/0 | http://www.rtkti.com/aboutmexel.html : - |

# Ozone

$O_3$ **CAS_#** 10028-15-6



Ozone is found in the atmosphere in varying proportions as it is produced continuously in the outer layers of the atmosphere by the action of solar UV radiation on the oxygen of the air. It is also formed locally in the air from lightning and electrical sparks. In freshwater, ozone is an excellent disinfectant and in seawater, ozone is used to control bacteria and viruses. Available as in gas form, in liquid form (below its boiling point of -112 deg. C), or in solid form (below its melting point of -193 deg. C)

**Other Names** Triatomic oxygen, trioxygen

**Trade_Names**

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | gas | U.S. EPA 1999 |
| pH | Ozone decomposes faster as pH increases but biocidal activity not influenced by pH | U.S. EPA 1999 |
| Specific gravity | 2.144 | CCOHS 2004 |
| Solubility in water | Slightly soluble (0.11 g/100 mL or 49.4% v/v at 0 deg C ; 0.06 g/100 mL at 20 deg C) | CCOHS 2004 |
| Solubility in water | sparingly soluble | U.S. EPA 1999 |
| Stability | Reacts with dissolved organics, iron(II), manganese(II), and sulphite very quickly. | Oemcke 1999 |
| Stability | decays rapidly at high pH and warm temperatures | U.S. EPA 1999 |
| Inactivation | Cell wall rupture (lysing) | Jackson 2003 |
| Inactivation | Production of halogens and injection of ionized air | Stewart 2003 |
| Inactivation | attacks bacterial membranes and disrupts enzymatic activity, and may also act on the nuclear material within cell. Virus inactivation is the virion capsid, particularly the proteins. RNA may also be the target | U.S. EPA 1999 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| All microroganisms | 1 mg/L | Jackson 2003 |
| Cryptosporidium parvum | 40 mg/L effective dose for drinking water | Biswas 2003 |
| Cryptosporidium parvum oocysts | 4-10 min*mg/L can achieve 2-log (99%) reduction | Oemcke 1999 |
| Cryptosporidium parvum oocysts | 1 ppm (1 mg/L) for 5 min achieved > 90% inactivation | Korich 1990 |
| Enterococci | ~2-log reduction: 30-50 mg/L | Gehr 2003 |
| Entrococcus seriolicida | 0.111 mg/L achieves 2-log (99%) reduction or 0.123 mg*min/L; 0.177 mg/L achieves 3-log (99.9%) reduction or 0.186 mg*min/L; 0.246 mg/L achieves 4-log reduction; 0.319 mg/L achieves 5-log reduction; 0.393 mg/L achieves 6-log reduction | Sugita 1992 |
| Escherichia coli | 0.6 ug/L dissolved ozone can achieve 4-log (99.99%) reduction in less than 1 minute with a residual of 9 ug/L at 12 degrees C. | U.S. EPA 1999 |
| fish | LC50: highly toxic | PAN 2004 |
| Giardia cysts | To achieve 0.5-log, 1.0-log, 1.5-log, 2.0-log, 2.5-log, 3.0-log inactivation: 0.23 mg-min/L, 0.48 mg-min/L, 0.72 mg-min/L, 0.95 mg-min/L, 1.2 mg-min/L, and 1.43 mg-min/L. | Cowley 1999 |
| Giardia muris | Inactivation at pH 8 and 15 deg C shows dependency between log kill and the initial concentration of microorganisms. The level of inactivation decreases as initial organism concentration decreases. | Hass 2003 |
| Giardia muris cysts | 2 min*mg/L can achieve 2-log (99%) reduction | Oemcke 1999 |
| Legionella pneumophila | 0.21 mg/L ozone can achieve 2-log (99%) removal within 5 min | U.S. EPA 1999 |
| molluscs | EC50: mortality | PAN 2004 |
| MS-2 | Less resistant than enterococci | Gehr 2003 |
| Mycobacterium tuberculosis | 0.21 mg/L ozone achieves 4-log (99.99%) reduction with >30 min contact time | U.S. EPA 1999 |
| Pasteurella piscicida | 2-log removal: 0.063 mg/L or 0.057 mg*min/L; 3-log removal: 0.089 mg/L or 0.084 mg*min/L; 4-log removal: 0.115 mg/L; 5-log removal: 0.140 mg/L; 6-log removal: 0.165 mg/L | Sugita 1992 |
| Perfringens | More resistant than enterococci | Gehr 2003 |
| Streptococcus faecalis | 0.21 mg/L ozone achieves 2-log (99%) reduction with contact time of >10 min | U.S. EPA 1999 |
| Vibrio anguillarum | 2-log removal: 0.081 mg*min/L; 3-log removal: 0.123 mg*min/L | Sugita 1992 |
| Viruses | To achieve 2-log, 3-log, 4-log inactivation: 0.5 mg-min/L, 0.8 mg-min/L, 1.0 mg-min/L, | Cowley 1999 |

| | |
|---|---|
| | respectively. |

**Environmental Acceptability**

| | | |
|---|---|---|
| Environmental Acceptibility | Brominated organics and bromate can have negative environmental impacts at low concentrations. | Oemcke 1999 |
| Byproducts | Oxygen, brominated organics; Brominated organics are naturally biodegradable | Jackson 2003 |
| Byproducts | Brominated organics, bromate, and bromines | Oemcke 1999 |
| Byproducts | organic acids and aldehydes. If bromide ion is present or chlorine added, halogenated DBPs may form | U.S. EPA 1999 |
| Effectiveness Factor | Ozone is more effective in freshwater systems. | Oemcke 1999 |
| Effectiveness Factor | As temperature increases, ozone becomes less soluble and less stable in water. | U.S. EPA 1999 |

**Shipboard Use**

| | | |
|---|---|---|
| Generation | Ozone is generated on-site, at its point of use usually by dissociation of molecular oxygen electrically (silent discharge) or photochemically (ultraviolet irradiation). | CCOHS 2004 |
| Generation | Ozone can be safely generated with on-site air. | Oemcke 1999 |
| Generation | should be generated at the point of use. Feed gas should be clean and dry with max dewpoint of -60 deg C. Relatively complex process | U.S. EPA 1999 |
| Storage | not easily stored | CCOHS 2004 |
| Handling | Even very low concentrations of ozone can be harmful to the upper respiratory tract and the lungs. | CCOHS 2004 |
| Handling | ozone is a toxic gas | U.S. EPA 1999 |
| Corrosivity | Attacks most metals including iron and mild steel. | CCOHS 2004 |
| Corrosivity | Hyprobromous acid will have little effect, which is what will be the result of controlled application of ozone; Oxidation of the steel if ozone application is not controlled | Jackson 2003 |
| Corrosivity | highly corrosive | U.S. EPA 1999 |
| Power Requirements | Usually single-phase 115/230 vac. Possibly three-phase 460 vac. | Jackson 2003 |
| Power Requirements | rate of 8 to 17 kWhr/kg O3 | U.S. EPA 1999 |
| Maintenance | Semi-annual service if the gas supply and ozonator units. Ususally 1 day twice per year. | Jackson 2003 |
| Maintenance | Regular visual inspections and reading the maintenance log. Annual change out of Ionz cells and chlorine generators. | Stewart 2003 |

**Laws and Regulations**

| Country_Region | Regulation | Web site |
|---|---|---|
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East Asian nations | East Asian Seas Action Plan | |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| European Union | Existing Substances Regulation 793/93/EEC | http://ecb.jrc.it/Legislation/1993R0793EC.pdf |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |

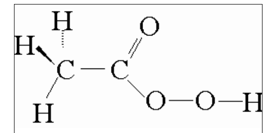
| | | |
|---|---|---|
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Occupational Safety and Health Act | http://www4.law.cornell.edu/uscode/29/ch15.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations


| | | |
|---|---|---|
| Biswas, K, S Craik, DW Smith, M Belosevic. 2003. | Synergistic inactivation of Cryptosporidium parvum using ozone followed by free chlorine in natural water | Water Research 37: 4737-4747 |
| CCOHS, , . 2004. | Cheminfo Profile for Ozone | http://www.intox.org/databank/documents/chemical/ozone/cie774.htm : - |
| Clark, RM, Sivagenesan, M., Rice, E. W., and Chen, J. 2002. | Development of a Ct equation for the inactivation of Cryptosporidium oocysts with ozone | Water Research 36: 3141-3149 |
| Cowley, G, . 1999. | Disinfection with Chlorine Dioxide | Sterling Pulp Chemicals : 1-9 |
| Gehr, R, M Wagner, P Veerasubramanian, P Payment. 2003. | Disinfection efficiency acid, UV and ozone after enhanced primary treatment of municipal wastewater | Water Research 37: 4573-4586 |
| Hass, CN, B Kaymak. 2003. | Effect of Initial Microbial Density on Inactivation of Giardia Muris by Ozone | Water Research 37: 2980-2988 |
| Jackson, J, . 2003. | Telephone conversation with James Jackson | GDT Corporation : - |
| Korich, DG, JR Mead, MS Madore, NA Sinclair, CR Sterling. 1990. | Effects of Ozone, Chlorine Dioxide, Chlorine, and Monochloramine on Cryptosporidium parvum Oocyst Viability | Applied and Environmental Microbiology 56: 1423-1428 |
| Oemcke, D, . 1999. | The Treatment of Ships' Ballast Water | EcoPorts Monograph Series 18: - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Stewart, J, . 2003. | Telephone conversation with Jon Stewart, Vice President of Sales | Marine Environmental Partners : - |
| Sugita, H, T Asai, K Hayashi, T Mitsuya, K Amanuma, Y Deguchi. 1992. | Application of Ozone Disinfection to Remove Enterococcus seriolicida, Pasteurella piscicida, and Vibrio anguillarum from Seawater | Applied Environmental Microbiology 58: 4072-4075 |
| U.S. EPA, , . 1999. | Alternative Disinfectants and Oxidants Guidance | EPA Report 815-R-99-014 : - |

# Peracetic Acid (Peroxyacetic Acid)

$C_2H_4O_3$ **CAS_#** 79-21-0



Available as a liquid.

**Other Names** Acetic peroxide; Acetyl hydroperoxide; Ethaneperoxoic acid; Monoperacetic acid; Peroxoacetic acid; Peroxyacetic acid

**Trade_Names** Peraclean®

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | liquid based on peroxy acetic acid | Fuchs 2001 |
| pH | pH of treated sea water is recuded from 8.2 to 6.1, due to acidic properties of peraclean | Fuchs 2001 |
| Solubility in water | very soluble in water | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| brine shrimp, Artemia salina, at four stages | levels above 350 ppm resulted in 100% mortality of all Artemia live stages. | Fuchs 2001 |
| coliforms | Intial concentration of 0.5-4 mg/L with 8-38 min contact time. Low contact time: 8-12 min, med contatc time: 20-26 min, high contact time of 36-39 min. | Veschetti 2003 |
| Everything down to 40 uM | With filtration, 50 ppm | Fredericks 2003 |
| fish | no LC50; immunological, mortality from EC50 | PAN 2004 |
| Fungi | population effects based on EC50 | PAN 2004 |
| Giardia muris | 90% inactivation has CT of 1.2 mg-min/L and for 99% inactiviation CT of 2.6 mg-min/L. When H2O2/O3 ratio is 0.2, 90% inactivation CT of 2.6 mg-min/L and for 99% inactivation CT of 5.2 mg-min/L | U.S. EPA 1999 |
| poliovirus | 99% inactivation requires hydrogen peroxide dose of 3,000 mg/L for 360 minutes or 15,000 mg/L for 24 minutes. | U.S. EPA 1999 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | not expected to adsorb to suspended solids and sediment in water based on an estimated Koc value of 4 | Hazardous Substances Data Bank 2004 |
| Byproducts | expected to hydrolyze slowly to acetic acid and hydrogen peroxide in water | Hazardous Substances Data Bank 2004 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | shelf life is at least 1 year. More than 90% of original activity present after 1 year stored at room temp. Available in 220 L drums, 1 m3 IBCs or 20 m3 bulk. | Fuchs 2001 |
| Storage | Store in a cool, dry, well-ventilated location. Separate from acids, alkalies, organic materials, heavy metals. Normally kept refrigerated outside or detached storage is preferred | Hazardous Substances Data Bank 2004 |
| Corrosivity | Corrosive to most metals, including aluminum | Hazardous Substances Data Bank 2004 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East Asian nations | East Asian Seas Action Plan | |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| European Union | Existing Substances Regulation 793/93/EEC | http://ecb.jrc.it/Legislation/1993R0793EC.pdf |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |

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|---|---|---|
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

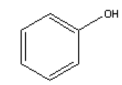
### Citations


| | | |
|---|---|---|
| Fredericks, R, . 2003. | Telephone conversation with Richard Fredericks, Vice President | Maritime Solutions : - |
| Fuchs, R, N. Steiner, I. deWilde, and M. Voigt. 2001. | Peraclean Ocean - a Potential Ballast Water Treatment Option | 1st International Ballast Water Treatment R&D Symposium, IMO, London : - |
| Gehr, R, M Wagner, P Veerasubramanian, P Payment. 2002. | Disinfection Efficiency of Peracetic Acid, UV and Ozone after Enhanced Primary Treatment of Municipal Wastewater | Water Research 37: 4573-4586 |
| Hazardous Substances Data Bank, , . 2004. | Peracetic Acid | National Library of Medicine Toxnet System : - |
| Oemcke, D, . 1999. | The Treatment of Ships' Ballast Water | EcoPorts Monograph Series 18: - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Sagripanti, J, A Bonifacino. 1996. | Comparative Sporicidal Effects of Liquid Chemical Agents | Applied Environmental Microbiology 62: 545-551 |
| Veschetti, E, D. Cutili, L Bonadona, R Briancesco, C Martini, G Cecchini, P anastasi, M Ottaviani. 2003. | Pilot-plant comparative study of peracetic acid and sodium hypochlorite wastewater disinfection | Water Research 37: 78-94 |

# Phenol

$C_6H_6O$ **CAS_#** 108-95-2

Available commercially as a liquid, but is a colorless solid when pure.




**Other Names** Phenylic acid; Carbolic acid; Benzene, hydroxy-; Phenyl hydroxide; Hydroxybenzene; Oxybenzene; monohydroxy benzene; monophenol; Phenyl alcohol; Phenic Acid; phenol alcohol;

**Trade_Names**

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | colorless acicular crystals or white crystal mass | Hazardous Substances Data Bank 2004 |
| Density | 1.071 g/cu cm | Hazardous Substances Data Bank 2004 |
| Solubility in water | 1 g/15 ml water | Hazardous Substances Data Bank 2004 |
| Stability | half-life about 9 days in saltwater | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| amphibians | slightly toxic | PAN 2004 |
| annelida | not acutely toxic | PAN 2004 |
| aquatic plants | not acutely toxic | PAN 2004 |
| crustaceans | slightly toxic | PAN 2004 |
| fish | slightly toxic | PAN 2004 |
| molluscs | not acutely toxic | PAN 2004 |
| nematodes and flatworms | not acutely toxic | PAN 2004 |
| phytoplankton | not acutely toxic | PAN 2004 |
| zooplankton | slightly toxic | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | will adsorb to suspended solids and sediments with Koc of 2900 to 3100. Log Kow 1.46 | Hazardous Substances Data Bank 2004 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | Material may be stowed "on deck" or "under deck" on cargo or passenger vessels. | DOT 2002 |
| Storage | Phenol and its solutions are flammable. Stored in closed containers protected from light and area well-ventilated. Prevent overheating and buildup of pressure in phenol containers | Hazardous Substances Data Bank 2004 |
| Handling | strong irritant to tissue. Vapor irritates respiratory system and eyes. Wear protective clothing, gloves, face shields, splash-proof safety goggles. | Hazardous Substances Data Bank 2004 |
| Ventilation | Poison hazard class. | DOT 2002 |
| Ventilation | Concentrations should not exceed 20 mg/cu m. | Hazardous Substances Data Bank 2004 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Canada | Canada Shipping Act - Part (XV): Pollutant Substances Regulations (CRC, c. 1458) | http://www.tc.gc.ca/acts-regulations/GENERAL/C/csa/regulations/050/csa052/csa52.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East Asian nations | East Asian Seas Action Plan | |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development | http://sedac.ciesin.org/entri/texts/mar |

| | | |
|---|---|---|
| | of the Marine and Coastal Environment of the Eastern Africa Region | ine.coastal.east.africa.1985.html |
| European Union | Existing Substances Regulation 793/93/EEC | http://ecb.jrc.it/Legislation/1993R0793EC.pdf |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |
| USA | Occupational Safety and Health Act | http://www4.law.cornell.edu/uscode/29/ch15.html |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations


| | | |
|---|---|---|
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| Hazardous Substances Data Bank, , . 2004. | Phenol | National Library of Medicine Toxnet System : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Sagripanti, J, A Bonifacino. 1996. | Comparative Sporicidal Effects of Liquid Chemical Agents | Applied Environmental Microbiology 62: 545-551 |

# Polyhexamethylene Biguanide (PHMB)

proprietary **CAS_#** 32289-58-0

Light blue liquid used as microbiocide, fungicide. Also available as a solid in tablet form.

**Other Names** Baquacil; Baquacil SB; poly hexamethlene biguanidine; polyhexamethylene diguanide chlorhydrate; PHMB; Poly (iminocarbonimidoyliminocarbonimidoylimino-1,6-hexanediyl), hydrochloride; Poly (iminoimidocarbonyliminoimidocarbonyliminohexamethylene) hydrochloride

**Trade_Names** Vantocil 1B; Baquacil SB; Baquacil; Cosmoquil CQPoly Clear Maxi Polish Swimming Pool Sanitizer and Algistat

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | 20% active ingredient in water solution | Alden Leeds 2002 |
| pH | 4.5 - 6.0 | Alden Leeds 2002 |
| Specific gravity | 1.04 | Alden Leeds 2002 |
| Solubility in water | Soluble | Alden Leeds 2002 |
| Stability | stable product | Alden Leeds 2002 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| annelida | LC50: slightly toxic | PAN 2004 |
| fish | LC50: moderately toxic | PAN 2004 |
| zooplankton | EC50: intoxication | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | Material is toxic to fish if released. | Alden Leeds 2002 |

## Shipboard Use

| | | |
|---|---|---|
| Application | Dosing equipment required | Alden Leeds 2002 |
| Storage | Store in Polyethylene, Polypropylene, Vinyl Polychloride and avoid temperatures below 43F to avoid freezing and do not store near Chlorine, Bromine, Ozone, Sodium Hydroxide, Copper, Silver, and most metals. | Alden Leeds 2002 |
| Handling | Gloves, goggles/glasses, and long sleeves should be worn when handling. | Alden Leeds 2002 |
| Ventilation | Local ventilation adequate | Alden Leeds 2002 |

## Laws and Regulations

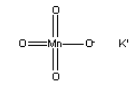
## Citations


| | | |
|---|---|---|
| Alden Leeds, , . 2002. | Poly Clear MSDS | http://www.aldenleeds.com/html/poly_clear.html : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |

# Potassium Permanganate

$KMnO_4$ **CAS_#** 7722-64-7

Dark green solid used as a metal stain as well as an oxidizer in a number of histological and electron microscope laboratory sample preparation procedures. Can also be made into a liquid solution.



**Other Names**

**Trade_Names**

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | crystalline solids | U.S. EPA 1999 |
| pH | better biocide under acidic conditions around pH of 6 | U.S. EPA 1999 |
| Density | 100 lb/ft3 | U.S. EPA 1999 |
| Solubility in water | 6.4 g/mL at 20 deg C | U.S. EPA 1999 |
| Inactivation | direct oxidation of cell material or specific enzyme destruction. | U.S. EPA 1999 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| annelida | LC50: very highly toxic | PAN 2004 |
| asiatic clams | juvenile clam doses range from 1.1 to 4.8 mg/L | U.S. EPA 1999 |
| coliform bacteria | doses of 1 and 2 mg/L needed contact time of 30 minutes. Doses of 3, 4, 5, and 6 mg/L needed contact time of 10 minutes. | U.S. EPA 1999 |
| coliform bacteria | high doses required. For coliforms, 2.5 mg/L for complete inactivation | U.S. EPA 1999 |
| crustaceans | LC50: moderately toxic | PAN 2004 |
| fish | LC50: moderately toxic | PAN 2004 |
| Legionella pneumophila | CT values for 99% (2-log) inactivation at pH 6 were 42.7 mg-min/L at a dose of 1 mg/L (contact time 42.7 min) and 41 mg-min/L at a dose of 5 mg/L (contact time 8.2 min). | U.S. EPA 1999 |
| molluscs | LC50: slightly toxic | PAN 2004 |
| MS-2 bacteriophage | 0.5 to 5 mg/L capable of obtaining 2-log inactivation with E. coli as host bacterium. At pH 6 and 8, a 2-log inactivation occurred after a contact time of 52 minutes and a residual of 0.5 mg/L. At residual of 5 mg/L, approx 7 and 13 minutes required for 2-log inactivation at pHs of 8 and 6, respectively. | U.S. EPA 1999 |
| phytoplankton | EC50: biochem, cell, mortality, population | PAN 2004 |
| Vibrio cholerae, Salm. Typhi, and Bact. Flexner | doses of 20 mg/L and contact time of 24 hours needed | U.S. EPA 1999 |
| viruses | 50 mg/L and contact time of 2 hours required for poliovirus. Dose of 5 mg/L and contact time of 33 minutes needed for 1-log inactivation of type 1 poliovirus. Higher inactivation rate at 23 deg C than at 7 deg C. | U.S. EPA 1999 |
| zebra mussels | continuous dosing of 0.5 to 2.5 mg/L | U.S. EPA 1999 |
| zooplankton | LC50: highly toxic | PAN 2004 |

**Environmental Acceptability**

| | | |
|---|---|---|
| Environmental Acceptibility | residual levels give water a pink color. | U.S. EPA 1999 |
| Byproducts | manganese dioxide as a precipitant. Microogranisms adsorb to these particles and settled. | U.S. EPA 1999 |
| Inhibitors | Presence of oxidizable organics and inorganics in water reduces disinfection effectiveness. | U.S. EPA 1999 |
| Effectiveness Factor | reaction rates depend on temperature, pH, and dosage. Better biocide under acidic conditions. Higher temperatures enhance bactericidal action. Long contact time required. | U.S. EPA 1999 |

**Shipboard Use**

| | | |
|---|---|---|
| Generation | generated on-site by using dry crystalline solids with makeup water. Costs ranges from \$1.50 to \$2.00 per pound (1997 costs). May need dry chemical feeder, storage hopper, and dust collector for large systems. Small systems may need dissolver/storage tank with mixers and a metering pump. | U.S. EPA 1999 |
| Storage | Must be stowed "on deck only" on a cargo vessel and on a passenger vessel carrying a number of passengers limited to not more than the larger of 25 passengers or one passenger per each 3 m of overall vessel length, but the material is prohibited on passenger vessels in which the limiting number of passengers is exceeded. Stow separated from ammonium compounds, cyanides, hydrogen peroxide, powdered metal, peroxides and superoxides. | DOT 2002 |
| Storage | easy to store | U.S. EPA 1999 |

| | | |
|---|---|---|
| Handling | Oxidizer Hazard Class; medium degree of danger presented by material. | DOT 2002 |
| Handling | can cause serious eye injury and is a skin and inhalation irritant so safety goggles and a face shield, gloves, coveralls and boots should be worn. | U.S. EPA 1999 |

**Laws and Regulations**

| Country_Region | Regulation | Web site |
|---|---|---|
| | East Asian Seas Action Plan | |
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Canada | Canada Shipping Act - Part (XV): Pollutant Substances Regulations (CRC, c. 1458) | http://www.tc.gc.ca/acts-regulations/GENERAL/C/csa/regulations/050/csa052/csa52.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
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| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
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| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
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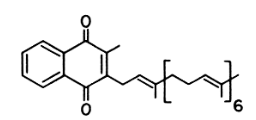
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean Region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

### Citations


| | | |
|---|---|---|
| Anderson, WB, CI Mayfield, DG Dixon, PM Huck. 2003. | Endotoxin Inactivation by Selected Drinking Waer Treatment Oxidants | Water Research 37: 4553-4560 |
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| U.S. EPA, , . 1999. | Alternative Disinfectants and Oxidants Guidance Manual | EPA 815-R-99-014 : - |

# SeaKleen (Vitamin K)

$C_{31}H_{40}O_2$ **CAS_#** 11032-49-8



Vitamin K2. Available in powder form and used as a biocide.

**Other Names** Menaquinone-4; Menatetrenone

**Trade_Names** SeaKleen

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | powder | Hyde OptiMarin 2004 |
| Solubility in water | soluble | Hyde OptiMarin 2004 |
| Stability | half life in fresh and salt waer is 18-24 hours depending upon dosage | Hyde OptiMarin 2004 |
| Stability | degrade relatively rapidly with half life of 16-30 hour. Remains in dissolved form in heavy sediment loads. | Wright 2001 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| bivalve larvae (zebra mussels) | 1 ppm | Wright 2001 |
| dinoflagellates and dinoflagellates cysts | 1 ppm. Complete chloroplast destruction within 2 hours. | Wright 2001 |
| Eurytemora, Cyprinodon eggs, dinoflagellates | low dose (1-2 ppm) | Hyde OptiMarin 2004 |
| fish larvae and eggs | 1 ppm | Wright 2001 |
| Isochrysis galbana, Neochloris, zebra mussel larva | very low dose (1-2 ppm) | Hyde OptiMarin 2004 |
| Leptocheirus plumulosus | 1 ppm | Wright 2001 |
| Oyster mussel larvae, E. coli, Cholera | low dose (1-2 ppm) | Hyde OptiMarin 2004 |
| Vibrio bacteria | 1 ppm | Wright 2001 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | environmental friendly compounds are discharged | Hyde OptiMarin 2004 |
| Environmental Acceptibility | does not present toxic threat to receiving waters. | Wright 2001 |
| Byproducts | environmentally friendly compounds | Hyde OptiMarin 2004 |
| Byproducts | non toxic compounds in marine environment | Wright 2001 |

## Shipboard Use

| | | |
|---|---|---|
| Generation | delivered as a soluble powder which is dissolved in water prior to being injected into the influent ballast water stream. | Hyde OptiMarin 2004 |
| Application | 1-2 g. per metric ton of ballast water. Retail at less than $0.2 per metric ton of ballast water treated. Dosing equipment retails at $1600. | Wright 2001 |
| Handling | no special training needed | Hyde OptiMarin 2004 |
| Size | complete system includes a chemical storage and handling system, mixing system, and accurate chemical metering system. | Hyde OptiMarin 2004 |
| Corrosivity | not corrosive to piping and ballast tanks | Hyde OptiMarin 2004 |

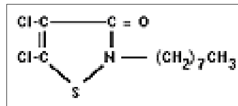
## Laws and Regulations

## Citations


| | | |
|---|---|---|
| Hyde OptiMarin, , . 2004. | SeaKleen Treatment | http://www.hydeweb.com/ballast/seakleen.htm : - |
| Wright, D, Rodger Dawson. 2001. | SeaKleen, a Potential Natural Biocide for Ballast Water Treatment | 1st International Ballast Water Treatment R&D Symposium, IMO, London : - |

# Sea-Nine

$C_{11}H_{17}Cl_2NOS$ **CAS_#** 64359-81-5



4,5-dichloro-2-n-octyl-4-isothiazonline-3-one (DCOI) supplied in 30% solution in xylene as commercial product

**Other Names** 4,5-dichloro-2-n-octyl-3(2H)-isothiazolone; 4,5-dichloro-2-octyl-3(2H)-isothiazolone

**Trade_Names** C-9211; DCOI; Duracide L Meldewcide; Kathon 287T; Kathon 5287; Kathon 930; Sea-Nine 211; Sea Nine 211; RH-25287

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | liquid solution | Rohm & Hass 2003 |
| Solubility in water | 6.5 mg/L at 20 deg C; log Kow = 2.8; log Koc = 3.2 | DEPA 2000 |
| Solubility in water | 4.7 g/m3 | Gandrass 2001 |
| Solubility in water | Koc = 15000 kg/L | Thomas 2003 |
| Stability | biological half-life may be estimated at 14 hours at 12° C ; The aerobic half-life of DCOI is very short in marine systems with sediment and seawater (< 1 hour) | DEPA 2000 |
| Stability | leaching rate = 1 (0.1-5) ug/cm2/day | Gandrass 2001 |
| Inactivation | Similar effects whether freshwater or seawater. | DEPA 2000 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| Algae | EC50 = 0.0139-0.036 mg/L for 4-5 days exposure | DEPA 2000 |
| Balanus amphitrite | LC50 with active ingredient (ai) = 0.34 ppm | Rohm & Hass 2003 |
| Bay Mussels | 48-hour LC50 (embryo) = 2 ug/L; 48-hour LC50 (larvae) = 2 ug/L | Kobayashi 2002 |
| Bluegill | 96-hour static LC50 (0.5-1.1 g fish) = 19.8 - 26.7 ppb (highly toxic) | PAN 2004 |
| Brown shrimp | juvenile shrimp 96-hour LC50 = 27 ppb highly toxic | PAN 2004 |
| Crustaceans | EC/LC50 = 0.0047-1.312 mg/L for 2-4 days; NOEC (reproduction) = 0.0006 mg/L (21 days) | DEPA 2000 |
| Daphnia magna | 48-hour EC50 = 5.22 ppb for flow-through | PAN 2004 |
| Diatom | 96-hour EC50 = 18 ppb | PAN 2004 |
| Ectocarpus siliculosis | (Algae) Minimum inhibitory concentration (MIC) with active ingredient (ai) = 0.2 ppm | Rohm & Hass 2003 |
| Enteromorpha intestinalis | (Algae) Minimum inhibitory concentration (MIC) with active ingredient (ai) = 0.1 ppm | Rohm & Hass 2003 |
| Fiddler crab | 15-cm crabs: 96-hour LC50 = 1700 ppb (moderately toxic) | PAN 2004 |
| Fish | LC50 = 0.0027-0.03 mg/L for 4 days; NOEC (early life stage) = 0.006 mg/L for 35 days exposure | DEPA 2000 |
| Mollusca | EC/LC50 = 0.0019-0.850 mg/L for 2-4 days exposure | DEPA 2000 |
| Opossum shrimp | 96-hour LC50 = 4.70 ppb (highly toxic) | PAN 2004 |
| Oysters | 48-hour EC50 = 24 ug/L | Kobayashi 2002 |
| Protozoa | 100% effect at 5 mg/L | DEPA 2000 |
| Sea Urchin | Higher concentrations of Sea-Nine induced cytolysis after cleavage, or produced a delay in development. Cleavage was delayed and development abnormal at medium and lower concentrations. | Kobayashi 2002 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | DCOI (EC/LC50) are lower than 10 µg/LN-(n-octyl) compared to its metabolite, malomanic acid, is several orders of magnitude lower as the lowest effect concentrations (LC50) are estimated to be between 90 and 160 mg/L. | DEPA 2000 |
| Environmental Acceptibility | More degradable and has a lower affinity to sediment as compared to TBT. | Gandrass 2001 |
| Environmental Acceptibility | Sea-Nine undergoes rapid biodegradation with a half life of less than an hour. | Thomas 2003 |
| Byproducts | metabolites (N-(n-octyl) malonamic acid and N-(n-octyl) acetamide) and carbon dioxide in seawater | DEPA 2000 |
| Inhibitors | Tolerance towards DCOI was detected during a short-term concentration response of photosynthesis inhibition in the microcosms with phytoplankton communities were exposed to 3.2-10 nM DCOI. The tolerance is possible due to the changes in communityy structure (changes in taxonomic composition of phytoplankton communities). For 32 nM DCOI, the half life is 2.5 days while for the 100 nM DCOI, the half life is 2.6 days. | Larsen 2003 |

## Shipboard Use

| | | |
|---|---|---|
| Storage | In a well ventilated area | Rohm & Hass 2003 |
| Handling | 30% solution is corrosive to skin and eyes and slightly toxic by oral and dermal routes of exposure; protective equipment must be worn to avoid contact with skin and eyes; respirator should be worn in areas that may have high vapor concentrations | Rohm & Hass 2003 |
| Ventilation | Explosive-proof local exhaust needed in storage and handling area | Rohm & Hass 2003 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| Canada | Canada Shipping Act - Part (XV): Pollutant Substances Regulations (CRC, c. 1458) | http://www.tc.gc.ca/acts-regulations/GENERAL/C/csa/regulations/050/csa052/csa52.html |

## Citations


| | | |
|---|---|---|
| DEPA, , . 2000. | Ecotoxicological Assessment of Antifouling Biocides and Nonbiocidal Antifouling Paints | www.mst.dk/udgiv/publications/2000/87-7944-084-3/html/kap03_eng.htm : - |
| Gandrass, J, W Salomons (Eds). 2001. | Dredged Material in the Port of Rotterdam - Interface between Rhine Catchment Area and North Sea (http://coast.gkss.de/aos/dredged_material/) | GKSS Research Centre : - |
| Kobayashi, N, H Okamura. 2002. | Effects of new antifouling compounds on the development of sea urchin | Marine Pollution Bulletin : 748-751 |
| Larsen, DK, I Wagner, K Gustavson, VE Forbes, T Lund. 2003. | Long-term effect of Sea-Nine on natural coastal phytoplankton communities assessed by pollution induced community tolerance | Aquatic Toxicology : 35- |
| PAN, , . 2004. | Pesticide Action Network Database | www.pesticideinfo.org/Detail_Chemical.jsp?Rec_Id=PC35757 : - |
| Rohm & Hass, , . 2003. | Formulating A Coating with SEA-NINE® | http://www.rohmhaas.com/seanine/index.html : - |
| Thomas, KV, M McHugh, M Hilton, M Waldock. 2003. | Increased persistence of antifouling paint biocides when associated with paint particles | Environmental Pollution : 153-161 |

# Silver Ions

$Ag^{+}$ **CAS_#** 15046-91-0

$Ag^+$ ions in solution or as insoluble silver complexes; can be electrolytically generated; used as a bacteriostat to destroy animal pathogenic bacteria

$Ag^{+}$

**Other Names**

**Trade_Names**

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | aqueous solution or insoluble silver complexes | Hazardous Substances Data Bank 2004 |
| Physical State | aqueous solution | Sistecam SA 2003 |
| pH | 1.45 | Sistecam SA 2003 |
| Specific gravity | 1.091 | Sistecam SA 2003 |
| Stability | Stable in solution. Light sensitive. | Sistecam SA 2003 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| amphibians | LC50: very highly toxic | PAN 2004 |
| Bacteria | 30 ppm induces a 6-log reduction within 2 minutes | Sistecam SA 2003 |
| crustaceans | EC50: accumulation | PAN 2004 |
| fish | LC50: highly toxic | PAN 2004 |
| Fungi | 30 ppm induces a 6-log inactivation within 10 minutes | Sistecam SA 2003 |
| molluscs | EC50: accumulation, behavior, biochem, growth, mortality | PAN 2004 |
| phytoplankton | EC50: accumulation, growth, mortality, physiology, population | PAN 2004 |
| Viruses | 30 ppm induces a 6-log reduction within 10 minutes | Sistecam SA 2003 |
| zooplankton | LC50: very highly toxic | PAN 2004 |

**Environmental Acceptability**

| | | |
|---|---|---|
| Effectiveness Factor | enhances disinfection properties of halogens (chlorine) | Sistecam SA 2003 |

**Shipboard Use**

| | | |
|---|---|---|
| Corrosivity | Not corrosive | Sistecam SA 2003 |
| Ventilation | No irritating fumes | Sistecam SA 2003 |

**Laws and Regulations**

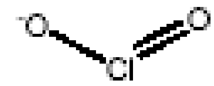
**Citations**


| | | |
|---|---|---|
| Abad, FX, RM Pinto, JM Diez, and A Bosch. 1994. | Disinfection of Human Enteric Viruses in Water by Copper and Silver Combination with Low Levels of Chlorine | Applied and Environmental Microbiology : 2377-2383 |
| Hazardous Substances Data Bank, , . 2004. | Silver Compounds | National Library of Medicine Toxnet System : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org / : - |
| Sistecam SA, , . 2003. | Axenohl™: Advanced Silver Ion Disinfection Technology | http://www.sistecam.com/Supportdocs/techdatasheet.PDF : - |

# Sodium Chlorite

$ClNaO_2$ **CAS_#** 7758-19-2

Bleaching agent as solution or solid flakes



**Other Names** Chlorite (sodium salt); Alcide ld; Chlorous acid, sodium salt;

**Trade_Names** Neo Silox D

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| fish | EC50: mortality | PAN 2004 |
| fish | LC50: not acutely toxic | PAN 2004 |
| fungi | EC50: population | PAN 2004 |
| molluscs | EC50: intoxication, mortality | PAN 2004 |
| phytoplankton | EC50: population | PAN 2004 |
| zooplankton | EC50: intoxication, mortality | PAN 2004 |
| zooplankton | LC50: highly toxic | PAN 2004 |

## Environmental Acceptability

## Shipboard Use

| | | |
|---|---|---|
| Storage | Material may be stowed "on deck" or "under deck" on cargo or passenger vessels. Stow separated from ammonium compounds, cyanides, and powdered metal. | DOT 2002 |
| Handling | Oxidizer hazard class; medium degree of danger presented by the material. | DOT 2002 |

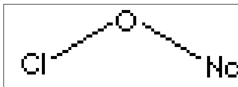
## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |

## Citations


| | | |
|---|---|---|
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |

# Sodium Hypochlorite




NaOCl **CAS_#** 7681-52-9

Industrial solutions available in water solutions containing approximately 12.5-15.75% sodium hypochlorite (12-15% available chlorine) are typically used as a disinfectant in water and wastewater systems.

**Other Names** Bleach; Chlorox; Hypochlorous acid, sodium salt; Javel water; Liquid bleach; Soda bleach; Sodium chloride oxide; Sodium oxychloride; Hychlorite; Sodium Chloride Oxide

**Trade_Names** Clorox; Javex

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | liquid | Hill Brothers 2003 |
| pH | 12 | Hill Brothers 2003 |
| pH | Maximum efficacy near neutral | Sagripanti 1996 |
| Specific gravity | 1.07 | Hill Brothers 2003 |
| Solubility in water | 29.3 g/100 g (0 deg C) in water | Hazardous Substances Data Bank 2004 |
| Solubility in water | 100% soluble | Hill Brothers 2003 |
| Stability | Decomposition of sodium hypochlorite takes place within a few seconds with the following salts: ammonium acetate, ammonium carbonate, ammonium nitrate, ammonium oxalate, and ammonium phosphate. | Hazardous Substances Data Bank 2004 |
| Stability | unstable above 40 deg C, in sunlight, or in contact with acid or metals | Hill Brothers 2003 |
| Stability | Decay rate = 0.;89 +/- 0.19 per day (r = 0.85) | Sagripanti 1996 |
| Inactivation | Bacteria and protozoa: breaches the cell wall and attacks nucleus; Viruses: attacks the DNA | Bolek 2003 |
| Inactivation | Attacks mucous membrane (i.e. cell walls) of nitrogen-bearing organisms | Harwell 2003 |
| Inactivation | Breaks up DNA with oxidation | Hill 2003 |
| Inactivation | Production of halogens and injection of ionized air | Stewart 2003 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| Bacillus subtillus spores | 0.05% inactivated >99.9% upon 30 min exposure at 20 deg C | Sagripanti 1996 |
| crustaceans | LC50: moderately toxic | PAN 2004 |
| Cryptosporidium parvum oocyst | Viability is not affected by 1.05 - 3 % chlorine as sodium hypochlorite for up to 18 hours. | Korich 1990 |
| Everything down to 50uM | ≤ 1-2 ppm | Hill 2003 |
| fish | LC50: highly toxic | PAN 2004 |
| Microorganisms | Depends on what is in the water. Ranges from 0.5 ppm to 50 ppm. | Bolek 2003 |
| molluscs | LC50: moderately toxic | PAN 2004 |
| nematodes and flatworms | LC50: slightly toxic | PAN 2004 |
| phytoplankton | LC50: moderately toxic | PAN 2004 |
| VEGETATIVE BACTERIA, VIRUSES | | Hazardous Substances Data Bank 2004 |
| zooplankton | LC50: moderately toxic | PAN 2004 |
| Zooplankton | ~10 ppm residual achieves 90% reduction after 2 hours treatment compared to control | Gracki 2002 |
| Zooplankton | ~10 ppm residual for 2 hours achieved >90% reduction | MI Env Sci Brd 2002 |
| Zooplankton, phytoplankton, viruses, larvae, bact. | Depends on level of harbor pollution. Minimum of 2 ppm and maximum of 18-20 ppm | Harwell 2003 |

**Environmental Acceptability**

| | | |
|---|---|---|
| Environmental Acceptibility | Residual chlorine can be toxic to aquatic organisms. | Gracki 2002 |
| Byproducts | Chlorine; sodium chlorate | CCHOS 2002 |
| Byproducts | Potential for leaching metals from the organic fraction of sediments. Amount of release would depend on contact time, amount of metals bound to sediments, amount of sediment, and fate of metals. Disinfection by-products (e.g., THMs) may form. | Gracki 2002 |

| | | |
|---|---|---|
| Byproducts | Sodium hypochlorite at .15% (EPA standards are 1%) and hydrogen gas below explosion level | Harwell 2003 |
| Byproducts | Salt and water are produced (NaOCl + H2) | Hill 2003 |

## Shipboard Use

| | | |
|---|---|---|
| Generation | Sodium hypochlorite can be produced directly by electrolysis of seawater or brine aboard ships | CCHOS 2002 |
| Generation | Can be purchased or generated on site. | Gracki 2002 |
| Application | Electrolosis and dosing equipment | CCHOS 2002 |
| Storage | Compatible tanks for liquid | CCHOS 2002 |
| Storage | Material may be stowed "on deck" or "under deck" on a cargo vessel or on a passenger vessel carrying a number of passengers limited to not more than the larger of 25 passengers, or one passenger per each 3 m of overall vessel length; "on deck only" on passenger vessels in which the number of passengers above is exceeded. Stow away from acids. | DOT 2002 |
| Handling | Corrosive to skin and eyes | CCHOS 2002 |
| Handling | Health: TOXIC, inhalation, ingestion, or skin contact with material may cause severe injury or death. Contact with molten substance may cause severe burns to skin and eyes. Avoid any skin contact | Hazardous Substances Data Bank 2004 |
| Size | System is made to conform to offshore platform standards. Made of stainless steel. Footprint is 1500mm W X 2600mm L X 2100mm H | Harwell 2003 |
| Size | Filter is modular and inline on intake (but it can be freestanding); Hypochlorite system has a footprint of 3'x5'x5' | Hill 2003 |
| Corrosivity | Concentrated sodium hypochlorite is corrosive to most metals | CCHOS 2002 |
| Corrosivity | Corrosive hazard class | DOT 2002 |
| Corrosivity | None | Harwell 2003 |
| Power Requirements | Small system: 220V AC Large system: 480V AC | Bolek 2003 |
| Power Requirements | 4 KW/kg; 3-phase power; voltage is adjusted according to vessel | Harwell 2003 |
| Ventilation | With electrolosis, hydrogen gas must be vented | CCHOS 2002 |
| Maintenance | Periodic preventative maintenance, loading brine tank, keeping recording logs | Bolek 2003 |
| Maintenance | Sulfamic acid cleaning (used as a boiler descaling material); lubricate pump and motor bearings | Harwell 2003 |
| Maintenance | Regular visual inspections and reading the maintenance log. Annual change out of Ionz cells and chlorine generators. | Stewart 2003 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Canada | Canada Shipping Act - Part (XV): Pollutant Substances Regulations (CRC, c. 1458) | http://www.tc.gc.ca/acts-regulations/GENERAL/C/csa/regulations/050/csa052/csa52.html |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East Asian nations | East Asian Seas Action Plan | |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| European Union | Existing Substances Regulation 793/93/EEC | http://ecb.jrc.it/Legislation/1993R0793EC.pdf |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Mediterranean Sea | Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea | http://www.unepmap.gr/pdf/dumping.pdf |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |

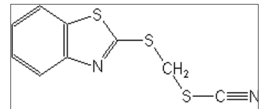
| | | |
|---|---|---|
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) | http://www4.law.cornell.edu/uscode/7/ch6.html |
| USA | Hazardous Materials Regulations (CFR49, Chap I, Subchap. C) | http://www.myregs.com/dotrspa/ |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

## Citations


| | | |
|---|---|---|
| Bolek, K, . 2003. | Telephone conversation with Katie Bolek, Marketing Manager | Miox Corporation : - |
| CCHOS, , . 2002. | Sodium hypochlorite solutions Chemical Profile | http://www.intox.org/databank/documents/chemical/sodhypoc/cie351.htm : - |
| DOT, , . 2002. | Hazardous Materials Table | 49 CFR 172.101, http://www.myregs.com/dotrspa/ : - |
| Gracki, JA, RA Everett, H Hack, PF Landrum, DT Long, BJ Premo, SC Raaymakers, GA Stapleton, KG Harrison. 2002. | Critical Review of a Ballast Water Biocides Treatment Demonstration Project Using Copper and Sodium Hypochlorite | Michigan Environmental Science Board, Lansing : - |
| Harwell, C, . 2003. | Telephone conversation with Christopher Harwell | Electrichlor : - |
| Hazardous Substances Data Bank, , . 2004. | Sodium Hypochlorite | National Library of Medicine Toxnet System : - |
| Hill Brothers, , . 2003. | Material Safety Data Sheet | http://www.desertbrand.com/msds/shypo.htm : - |
| Hill, D, . 2003. | Telephone conversation with David Hill | Severn-Trent : - |
| Korich, DG, JR Mead, MS Madore, NA Sinclair, CR Sterling. 1990. | Effects of Ozone, Chlorine Dioxide, Chlorine, and Monochloramine on Cryptosporidium parvum Oocyst Viability | Applied and Environmental Microbiology 56: 1423-1428 |
| Michigan Environmental Science Board, , . 2002. | Critical Review of a Ballast Water Biocides Treatment Demonstration Project using Copper and Sodium Hypochlorite | A Science Report to Governor John Engler : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Sagripanti, J, A Bonifacino. 1996. | Comparative Sporicidal Effects of Liquid Chemical Agents | Applied Environmental Microbiology 62: 545-551 |
| Stewart, J, . 2003. | Telephone conversation with Jon Stewart, Vice President of Sales | Marine Environmental Partners : - |

# TCMTB

$C_9H_6N_2S_3$ **CAS_#** 21564-17-0




reddish viscous and emulsifiable liquid commonly used as a fungicide in soil and seed treatment

**Other Names** 2-(Benzothiazolylthio)methyl thiocyanate; 2-(Thiocyanomethylthio)benzothiazole; 2-(Thiocyanometylthio)benzothiazole (TCMTB); mercaptobenzothiazonel;

**Trade_Names** Busan; Busan 30; Busan 44; Buxan 72; Busan 74; TCMTB

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | liquid | Cornell University 1985 |
| Solubility in water | practically insoluble in water | Cornell University 1985 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| Bluegill sunfish | 96-hour LC50 = 0.047 ppm using 60% formulation (Busan 72) | Cornell University 1985 |
| fish | very highly toxic | PAN 2004 |
| molluscs | slightly toxic | PAN 2004 |
| Rainbow trout | 96-hour LC50 = 0.029 ppm using 60% formulation (Busan 72) | Cornell University 1985 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | Anaerobic half life of 1.5 days for TCMTB and aerobic half life of 31-36 days. TCMTB is rapidly degraded in anaerobic marine sediments when compared to seawater | Thomas 2003 |

## Shipboard Use

| | | |
|---|---|---|
| Handling | Wear rubber gloves and goggles and avoid contact with this product. | Cornell University 1985 |

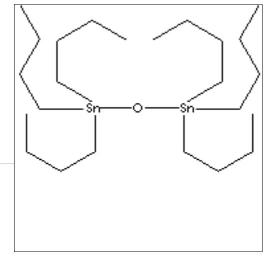
## Laws and Regulations

## Citations


| | | |
|---|---|---|
| Cornell University, , . 1985. | TCMTB (Busan) Chemical Profile 2/85 | http://pmep.cce.cornell.edu/profiles/ : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org/ : - |
| Thomas, KV, M McHugh, M Hilton, M Waldock.. 2003. | Increased persistence of antifouling paint biocides when associated with paint particles | Environmental Pollution 123: 153-161 |

# Tributyltins (TBT)

$C_{24}H_{54}OSn_2$ **CAS_#** 56-35-9




Organotin exists in the form of monobutyltin (MBT), dibutyltin (DBT), and tributyltin (TBT). TBT degrades into DBT and DBT degrades into MBT.

**Other Names** bis(tributyltin) oxide [CAS_# indicated]; butinox; hexabutyldistannoxane; TBTO

**Trade_Names**

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | liquid | NSC 2004 |
| pH | strong base | NSC 2004 |
| Solubility in water | soluble in hot water | NSC 2004 |
| Inactivation | Chronic toxic effects of TBT such as calcification anomalies in oyster and imposex in gastropods occur at a few ng TBT/L. The toxic concentrations of TVT at embryonic and early life stages of aquatic organisms lie in the range of a few ug/L. TBT into marine environments wwas generated by washdown furing repainting of ships in dry-dock facilities. Antifouling paints applied on boats and ships and effluents from dry-dock facilities are major sources of BTs. TBT was the highest concentration. TBT accumulated in the surface microlayers poses adverse effects on intertidal organisms, particularly their larvae which are more susceptible to toxic effect. | Hong 2002 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| Acartia Tonsa | Environmental concentrations of TBT of 20 to 100 ng/L. Acute toxicity of 0.47 ug/L at 18% salinity and 0.24 ug/L at 28% salinity. Concentrations as low as 0.6 ug/L was found to be toxic for Mercenaria mercenaria. At 0.6 ug/L inhibit growth of O. edulis for 50% | Kusk 1997 |
| Algae | EC50 values between 1-170 nM reported as indicators, based on various approaches employing growth or photosynthesis of algal cultures or phytoplankton communities. | Dahl 1996 |
| Anthocidaris crassispina | 10 mg/L induced low rates of fertilization and cleavage, cytolisis occurred. 0.001-1 mg/L: cleavage and normal development rates increased or decreased depending on the actual concentration; development delays and abnormal developments also appeared to be similarly affected. 0.01-0.1 ng/L (low dose) increased normal development rates. | Kobayashi 2002 |
| Hemicentrotus pulcherrimus | 10 mg/L induced low rates of fertilization and cleavage, cytolisis occurred. 0.001-1 mg/L: cleavage and normal development rates increased or decreased depending on the actual concentration; development delays and abnormal developments also appeared to be similarly affected. 0.01-0.1 ug/L (low dose) increased normal development rates. | Kobayashi 2002 |
| Mytilus edulis | TBT concentrations increased with decreasing water depth and with length of mussel living in intertidal and subsurface zones. | Hong 2002 |
| Nucillus lapillus | TBT concentrations <0.5 ng/L have been shown to cause imposex. | Connelly 2001 |
| Periphyton | Detected TBT values as the first effect on periphyton communities was 0.3-0.6 nM. | Dahl 1996 |
| T. bronni | 10 to 20 ng/L TBT could cause imposex. | Bech 2002 |
| T. clavigera | 10 to 20 ng/L TBT could cause imposex. | Bech 2002 |

**Environmental Acceptability**

| | | |
|---|---|---|
| Environmental Acceptibility | TBT degrades to DBT in sediments which is more readily desorbed from the sediments. This desorption and increased mobility would result in an increase of the DBT:TBT ratio over time. | Connelly 2001 |
| Environmental Acceptibility | TBT interferes with energy metabolism in both chlorophlasts and mitochondria where they act either as ionophores; facilitating the halide/hydroxyl exchange across membrane or as energy transfer inhibitores binding to or in the area of the coupling factor. Both cases, ATP synthesis will be impaired. TBT can also inhibit DNA, RNA, and protein systhesis in rat thymocytes. TBT also inhibits mediated hemolysis of human erythrocytes. EC20 of photosynthesis inhibition: 4-16 nM; EC50 of photosynthesis inhibitions: 16-69 nM. | Dahl 1996 |
| Environmental Acceptibility | half life 1 to 2 weeks | Kusk 1997 |
| Byproducts | Reacts with inorganic and organic acids forming non-conducting, water-insoluble compounds. | NSC 2004 |
| Effectiveness Factor | Maximum no effect concentration = 10 ng/L (for all organisms??) | Kobayashi 2002 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| Australia | Anti-Fouling Legislation | |
| Baltic area | Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) | http://www.helcom.fi/convention/conventionframe.html |
| Canada | Anti-Fouling Legislation | |
| Central America, Northwest South America | Northeast Pacific Action Plan | http://www.unep.ch/seas/main/nep/nepape.html |
| East Asian nations | East Asian Seas Action Plan | |
| East coastal Africa | Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region | http://sedac.ciesin.org/entri/texts/marine.coastal.east.africa.1985.html |
| European Union | Biocidal Products Directive 98/8/EC (Anti-fouling) | http://europa.eu.int/comm/environment/biocides/ |
| Hong Kong | Anti-Fouling Legislation | |
| IMO | IMO Anti-Fouling Systems Convention | http://www.imo.org/Conventions/mainframe.asp?topic_id=529 |
| Japan | Anti-Fouling Legislation | |
| Korea | Anti-Fouling Legislation | |
| Malta | Anti-Fouling Legislation | |
| Mediterranean Sea | Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) | http://www.unep.ch/seas/main/med/medconvi.html |
| Mediterranean Sea | Protocol Concerning Mediterranean Specially Protected Areas | http://sedac.ciesin.org/entri/texts/acrc/mspecp.txt.html |
| Nations bordering the Red Sea or the Gulf of Aden | Jeddah Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment | http://www.unep.ch/seas/main/persga/convtext.html |
| Nations of the South Pacific | Noumea Convention for the Protection of Natural Resources and Environment of the South Pacific Region | |
| Nations surrounding Persian Gulf | Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution | http://sedac.ciesin.org/entri/texts/kuwait.marine.pollution.1978.html |
| NE Atlantic | Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris Convention) | http://www.ospar.org/eng/html/convention/welcome.html |
| Netherlands | Anti-Fouling Legislation | |
| New Zealand | Anti-Fouling Legislation | |
| North and South Korea, Japan, China, Russian Federation | Northwest Pacific Action Plan | |
| South Asia | South Asian Seas Action Plan | |
| Sweden | Anti-Fouling Legislation | |
| UK | Anti-Fouling Legislation | |
| United Nations | United Nations Convention on the Law of the Sea | http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm |
| USA | Anti-Fouling Legislation | http://www4.law.cornell.edu/uscode/ |

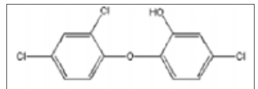
| | | |
|---|---|---|
| | | 33/ch37.html |
| USA | Clean Water Act | http://www.epa.gov/region5/water/pdf/ecwa.pdf |
| USA | Ocean Dumping Act (MPRSA) | http://www4.law.cornell.edu/uscode/33/ch27.html |
| USA | Organotin Antifouling Paint Control (33 U.S.C. 2401) | http://www4.law.cornell.edu/uscode/33/2401.html |
| West coastal Africa | Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region | http://sedac.ciesin.org/entri/register/reg-112.rrr.html |
| Western coastal nations of Central and South America | Lima Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific | http://fletcher.tufts.edu/multi/texts/bh809.txt |
| Wider Caribbean region | Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region | http://www.cep.unep.org/pubs/legislation/cartxt.html |

### Citations


| | | |
|---|---|---|
| Bech, M, . 2002. | Imposex and tributyltin contamination as a consequence of the establishment of a marina, and increasing yachting activities at Phuket Island, Thailand | Environmental Pollution 117: 421-429 |
| Connelly, DP, JW Readman, AH Knap, J Davies. 2001. | Contamination of the Coastal Waters of Bermuda by Organotins and the Triazine Herbicide Iragarol 1051 | Marine Pollution Bulletin 42: 677-688 |
| Dahl, B, H Blanck. 1996. | Pollution-induced community tolerance (PICT) in periphyton communities established under tri-n-butyltin (TBT) stress in marine microcosms | Aquatic Toxicology : 305-325 |
| Hong, HK, S Takahashi, BY Min, S Tanabe. 2002. | Butyltin residues in blue mussels (Mytilus edulis) and arkshells (Scapharca brughtonii) collected from Korean coastal waters | Environmental Pollution 117: 475-486 |
| Kobayashi, N, H Okamura. 2002. | Effects of new antifouling compounds on the development of sea urchin | Marine Pollution Bulletin : 748-751 |
| Kusk, KO, S Petersen. 1997. | Acute and Chronic Toxicity of Tributylin and Linear Alkylbenzene Sulfonate to the Marine Copepod Acartia Tonsa | Environmental Toxicology and Chemistry 16: 1629-1633 |
| NSC, , . 2004. | Tributyltin and Associated Chemicals Backgrounder | www.nsc.org/library/chemical/tributyl.htm : - |

# Triclosan

$C_{12}H_7Cl_3O_2$ **CAS_#** 3380-34-5




chlorinated phenol used as an antimicrobial agent, which is widely used in personal care products such as shampoos, soaps, cosmetics, lotions and toothpaste.

**Other Names** TCS, 5-chloro-2-(2,4-dichloro-phenoxy)-phenol, Phenol, 5-chloro-2-(2,4-dichlorophenoxy)-

**Trade_Names** Aquasept, CH-3635, Gamophen, Lexol 300, Irgasan DP-300, Irgasan, Sapoderm, SterZac

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Solubility in water | 12 mg/L; log Kow = 4.8; Koc = 47,454 mL/g | Danish EPA 2003 |
| Solubility in water | 10 mg/L in distilled water at 20 C | McAvoy 2002 |
| Stability | degradable under aerobic conditions but only little or no removal of Triclosan occurred during anaerobic sludge digestion | Danish EPA 2003 |
| Inactivation | does not affect the treatment processes at levels up to 2 mg/L in the influent | Danish EPA 2003 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| fish | highly toxic | PAN 2004 |
| gram negative and gram positive bacteria | exhibits a broad-spectrum bacteriostatic activity | McAvoy 2002 |
| zooplankton (water flea 24-hr) | 48-hr EC50 intoxication at min conc of 390 ug/L and max conc of 560 ug/L and mean of 180 ug/L | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Environmental Acceptibility | auatic photolysis: 41 min. half-life at pH 7 and 25°C | Danish EPA 2003 |
| Environmental Acceptibility | rapidly biodegradable in the soil environment half life from 15-35 days | McAvoy 2002 |
| Byproducts | may be biotransformed to a more slowly degradable methoxy-triclosan(TCS-Ome; 5-chloro-2-[2,4-dichloro-phenoxyl]-anisole) intermediate in wastewater treatment system. Exposure concentrations of TCS and its biotransformation by-products are expected to be low in the aquatic environment. | McAvoy 2002 |

## Shipboard Use

## Laws and Regulations

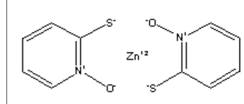
## Citations


| | | |
|---|---|---|
| Danish EPA, , . 2003. | Fate and Effects of Triclosan | Environmental Project no. 861 http://www.mst.dk/ : - |
| McAvoy, D, B Schatowitz, M Jacob, A Hauk, WS Eckhoff. 2002. | Measurement of Triclosan in Wastewater Treatment Systems | Environmental Toxicology 21: 1323-1329 |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org / : - |

# Zinc Pyrithione

$C_{10}H_8N_2O_2S_2Zn$ **CAS_#** 013463-41-

Available as a solid.




**Other Names** Pyrithione zinc; Zinc 2-mercaptopyridine N-oxide; Zinc pyridine-2-thiol 1-oxide; Zinc 1-hydroxy-2-pyridinethione; 2-Mercaptopyridine-1-oxide, zinc salt; Zinc, bis(1-hydroxy-2(1H)-pyridinethionato)-(8CI)

**Trade_Names**

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | powder form | Hazardous Substances Data Bank 2004 |
| Solubility in water | not soluble | Hazardous Substances Data Bank 2004 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| Anthocidaris crassispina | Fertilization and cleavage very high at all concentrations; however, cytolisis or delay in development occurred at 1, 0.1, 0.01, 0.001 pg/L. Various abnormal plutei ocurred at concentration of 0.0001 pg/L. | Kobayashi 2002 |
| Hemicentrotus pulcherrimus | Fertilization and cleavage very high at all concentrations; however, cytolisis or delay in development occurred at 1, 0.1, 0.01, 0.001 pg/L. Various abnormal plutei ocurred at concentration of 0.0001 pg/L. | Kobayashi 2002 |

**Environmental Acceptability**

**Shipboard Use**

**Laws and Regulations**

**Citations**

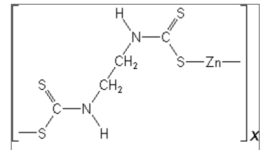


| | | |
|---|---|---|
| Hazardous Substances Data Bank, , . 2004. | Pyrithione zinc | National Library of Medicine Toxnet System : - |

# Zineb

$C_4H_6N_2S_4Zn$ **CAS_#** 12122-67-7

fungicide; Dithiocarbamate, inorganic zinc. Available as a light-colored powder or crystal.



**Other Names** Carbamodithioic acid; 1,2-ethanediylbis-; zinc salt; Cineb, Dithane Z-78, Ethylenebis(dithiocarbamic acid); [Ethylene bis(dithiocarbamate)]zinc; Micide; Aaphytora; Aspor; Bercema; Blizene, Carbadine; CHEM zineb; Cineb; Dithane Z; Dithiamina; ENT 14; Novozin; Parzate C; Phytox; Tanazon; Zidan; Zebtox

**Trade_Names** Zineb, Zinebe, Lonacol, Aspor, Chem Zineb, Dipher, Discon Z, Zinosan

| Physiochemical Properties | Value or Comment | Citation |
|---|---|---|
| Physical State | light-colored powder or crystal | Extension Toxicology Network 1996 |
| Solubility in water | 10mg/L at 25 deg C | Extension Toxicology Network 1996 |
| Stability | Unstable in water, hydrolyzes rapidly. Koc is 1000 (estimated); Kow is <1.3010 at 20 deg C | Extension Toxicology Network 1996 |

| Target Organism | Treatment Dosage | Citation |
|---|---|---|
| amphibians | LC50: not acutely toxic | PAN 2004 |
| annelida | LC50: highly toxic | PAN 2004 |
| crustaceans | LC50: slightly toxic | PAN 2004 |
| fish | LC50: slightly toxic | PAN 2004 |
| fish | moderately toxic. The 96-hour LC50 in perch is 2 mg/L | Extension Toxicology Network 1996 |
| molluscs | LC50: not acutely toxic | PAN 2004 |
| phytoplankton | EC50: growth, population | PAN 2004 |
| zooplankton | LC50: slightly toxic | PAN 2004 |

## Environmental Acceptability

| | | |
|---|---|---|
| Byproducts | ETU and other compounds | Extension Toxicology Network 1996 |

## Shipboard Use

| | | |
|---|---|---|
| Generation | was available in the U.S. as wettable powder and dust formulations. Zineb is formed by combining nabam and zinc sulfate in the spray tank. | Extension Toxicology Network 1996 |

## Laws and Regulations

| Country_Region | Regulation | Web site |
|---|---|---|
| USA | formerly registered in the U.S. as a General Use Pesticide. All tolerances for zineb in agricultural commodities in the U.S. (except grapes used in winemaking) were revoked, effective 12/31/94. The tolerance for grapes in winemaking was revoked in 1997. | |

## Citations


| | | |
|---|---|---|
| Extension Toxicology Network, , . 1996. | Pesticide Information Profiles | Oregon State University : - |
| PAN, , . 2004. | Pesticide Action Network Database | http://www.pesticideinfo.org / : - |